

FUNDAMENTALS OF

Organic Chemistry

SEVENTH EDITION

John McMurry

Cornell University

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Study Guide and Solutions Manual

Fundamentals of Organic Chemistry

SEVENTH EDITION

John McMurry

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Prepared by

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A full description of how a reaction occurs is called its **mechanism**. There are two kinds of organic mechanisms: polar and radical. **Polar reactions**, the most common kind, involve even-electron species and occur when an electron-rich reagent, or **nucleophile**, donates an electron pair to an electron-poor reagent, or **electrophile**, in forming a new bond. **Radical reactions** involve odd-electron species and occur when each reactant donates one electron in forming a new bond.

A reaction can be described pictorially by using an energy diagram, which follows the course of the reaction from reactant to product. Every reaction proceeds through a **transition state**, which represents the highest-energy point reached and is a kind of activated complex between reactants. The amount of energy needed by reactants to reach the transition state is the **activation energy, E_{act}** . The larger the activation energy, the slower the reaction. A **catalyst** can sometimes be used to increase the rate of a reaction by providing an alternative mechanistic pathway.

Many reactions take place in more than one step and involve the formation of an **intermediate**. An intermediate is a species that is formed during the course of a multistep reaction and that lies in an energy minimum between two transition states. Intermediates are more stable than transition states but are often too reactive to be isolated.

Exercises

Visualizing Chemistry

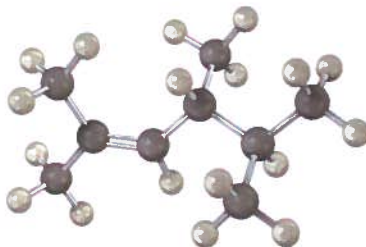
(Problems 3.1–3.19 appear within the chapter.)



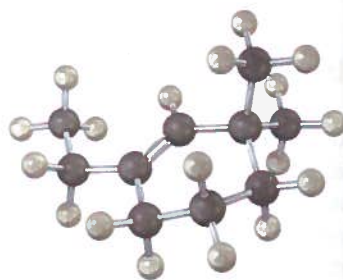
Interactive versions of these problems are assignable in OWL.

3.20 Name the following alkenes, and convert each drawing into a skeletal structure.

(a)

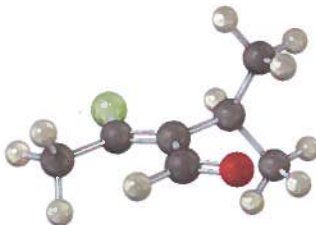


(b)

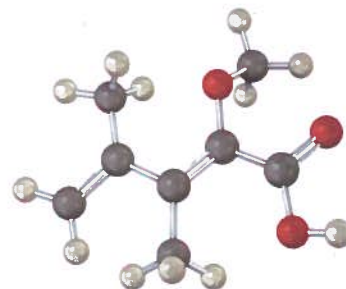


3.21 Assign *E* or *Z* stereochemistry to each of the following alkenes, and convert each drawing into a skeletal structure (red = O, yellow-green = Cl).

(a)



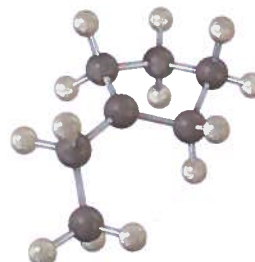
(b)



- 3.22 The following alkyl chloride can be prepared by addition of HCl to two different alkenes. Name and draw the structures of both (yellow-green = Cl).



- 3.23 The following carbocation is a possible intermediate in the electrophilic addition of HCl with two different alkenes. Write structures for both.



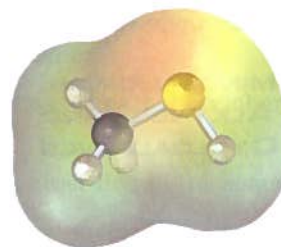
- 3.24 Electrostatic potential maps of (a) formaldehyde (CH_2O) and (b) methanethiol (CH_3SH) are shown. Is the formaldehyde carbon atom likely to be electrophilic or nucleophilic? What about the methanethiol sulfur atom? Explain.

(a)



Formaldehyde

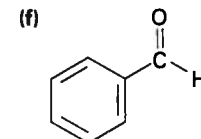
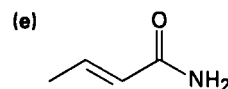
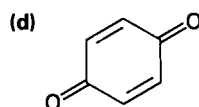
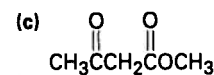
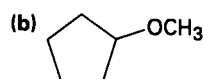
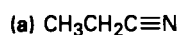
(b)



Methanethiol

Additional Problems

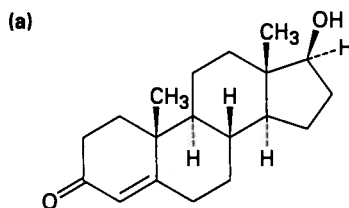
- 3.25 Predict the direction of polarization of the functional groups in each of the following molecules.



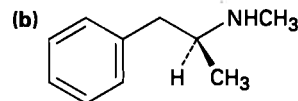
3.26 Which of the following are likely to behave as electrophiles and which as nucleophiles?

- (a) Cl^- (b) $\text{N}(\text{CH}_3)_3$ (c) Hg^{2+} (d) CH_3S^- (e) CH_3^+

3.27 Identify the likely electrophilic and nucleophilic sites in each of the following molecules:

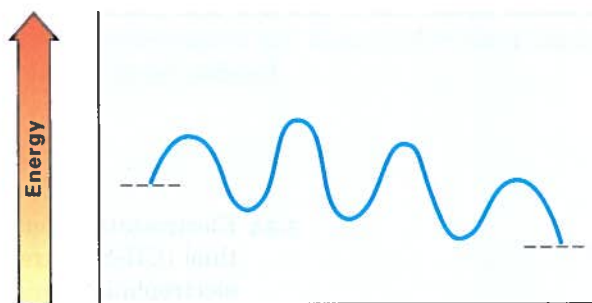


Testosterone



Amphetamine

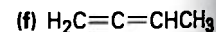
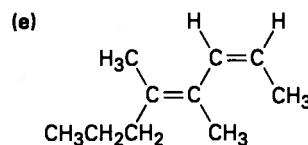
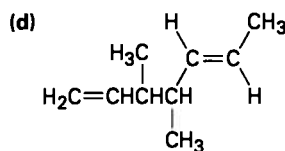
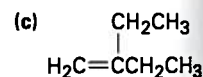
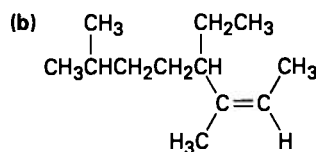
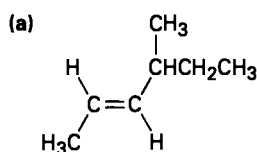
3.28 Look at the following energy diagram for an enzyme-catalyzed reaction:



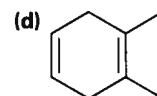
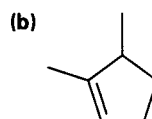
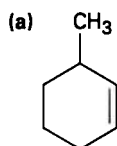
- (a) How many steps are involved?
 (b) Which is the fastest step, and which is the slowest?

NAMING ALKENES, ALKYNES, AND CYCLOALKENES

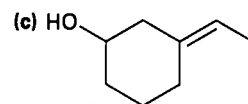
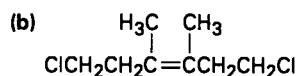
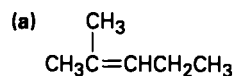
3.29 Name the following alkenes:



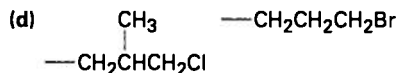
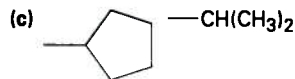
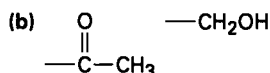
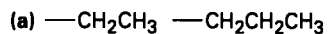
3.30 Name the following cycloalkenes:



- 3.31 Draw structures corresponding to the following IUPAC names:
 (a) 3-Propylhept-2-ene (b) 2,4-Dimethylhex-2-ene
 (c) Octa-1,5-diene (d) 4-Methylpenta-1,3-diene
 (e) *cis*-4,4-Dimethylhex-2-ene (f) (*E*)-3-Methylhept-3-ene
- 3.32 Draw the structures of the following cycloalkenes:
 (a) *cis*-4,5-Dimethylcyclohexene (b) 3,3,4,4-Tetramethylcyclobutene
- 3.33 The following names are incorrect. Draw each molecule, tell why its name is wrong, and give its correct name.
 (a) 1-Methylcyclopent-2-ene (b) 1-Methylpent-1-ene
 (c) 6-Ethylcycloheptene (d) 3-Methyl-2-ethylcyclohexene
- 3.34 Correct the following pre-1993 names to current names, and draw each structure:
 (a) 2,5-Dimethyl-3-hexyne (b) (*Z*)-3-Methyl-2-pentene
- 3.35 Which of the following molecules show *cis-trans* isomerism?

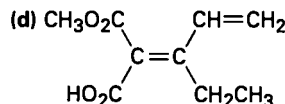
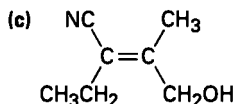
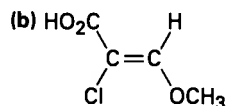
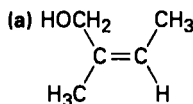


- 3.36 Draw and name molecules that meet the following descriptions:
 (a) An alkene, C_6H_{12} , that does not show *cis-trans* isomerism
 (b) The *E* isomer of a trisubstituted alkene, C_6H_{12}
 (c) A cycloalkene, C_7H_{12} , with a tetrasubstituted double bond
- 3.37 Neglecting *cis-trans* isomers, there are five substances with the formula C_4H_8 . Draw and name them.
- 3.38 Which of the molecules you drew in Problem 3.37 show *cis-trans* isomerism? Draw and name their *cis-trans* isomers.
- 3.39 Cyclodecene can exist in both *cis* and *trans* forms, but cyclohexene cannot. Explain.
- 3.40 Rank the following pairs of substituents according to the sequence rules:



- 3.41 Rank the following sets of substituents according to the sequence rules:
 (a) $-\text{CH}_3$, $-\text{Br}$, $-\text{H}$, $-\text{I}$
 (b) $-\text{OH}$, $-\text{OCH}_3$, $-\text{H}$, $-\text{CO}_2\text{H}$
 (c) $-\text{CH}_3$, $-\text{CO}_2\text{H}$, $-\text{CH}_2\text{OH}$, $-\text{CHO}$
 (d) $-\text{CH}_3$, $-\text{CH}=\text{CH}_2$, $-\text{CH}_2\text{CH}_3$, $-\text{CH}(\text{CH}_3)_2$

3.42 Assign *E* or *Z* stereochemistry to the following alkenes:



3.43 Draw and name the six C_5H_{10} alkene isomers, including *E*, *Z* isomers.

3.44 Draw and name all possible stereoisomers of hepta-2,4-diene.

3.45 Menthene, a hydrocarbon found in mint plants, has the IUPAC name 1-isopropyl-4-methylcyclohexene. What is the structure of menthene?

ENERGY DIAGRAMS

3.46 If a reaction has $E_{\text{act}} = 15 \text{ kJ/mol}$, is it likely to be fast or slow at room temperature? Explain.

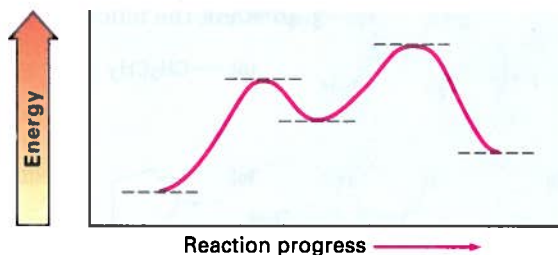
3.47 Draw an energy diagram for a two-step reaction that releases energy and whose first step is faster than its second step. Label the parts of the diagram corresponding to reactants, products, transition states, intermediates, activation energies, and overall energy change.

3.48 Draw an energy diagram for a two-step reaction whose second step is faster than its first step.

3.49 Draw an energy diagram for a reaction whose products and reactants are of equal stability.

3.50 Describe the difference between a transition state and a reaction intermediate.

3.51 Consider the energy diagram shown:



(a) Indicate the overall energy change for the reaction. Is it positive or negative?

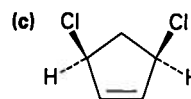
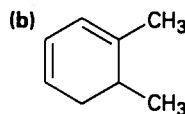
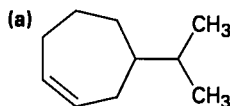
(b) How many steps are involved in the reaction?

(c) Which step is faster?

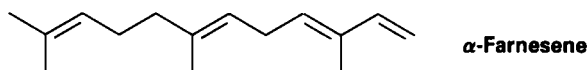
(d) How many transition states are there? Label them.

GENERAL PROBLEMS

3.52 Name the following cycloalkenes:



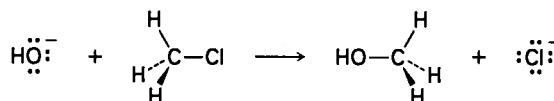
3.53 α -Farnesene is a constituent of the natural waxy coating found on apples. What is its IUPAC name?



3.54 Indicate *E* or *Z* stereochemistry for each of the double bonds in α -farnesene (see Problem 3.53).

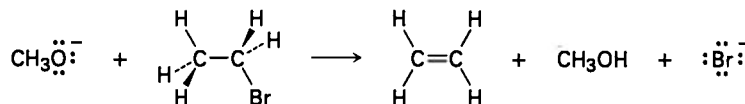
3.55 Reaction of 2-methylpropene with HCl might, in principle, lead to a mixture of two products. Draw them.

3.56 Hydroxide ion reacts with chloromethane in a single step according to the following equation:



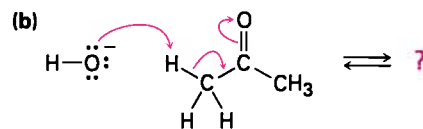
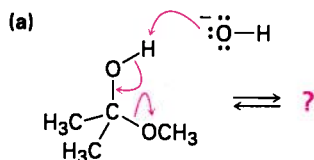
Identify the bonds broken and formed, and draw curved arrows to represent the flow of electrons during the reaction.

3.57 Methoxide ion (CH_3O^-) reacts with bromoethane in a single step according to the following equation:

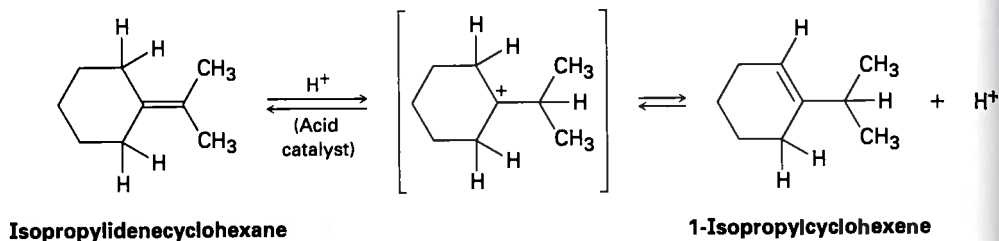


Identify the bonds broken and formed, and draw curved arrows to represent the flow of electrons during the reaction.

3.58 Follow the flow of electrons indicated by the curved arrows in each of the following reactions, and predict the products that result:



- 3.59** When isopropylidenecyclohexane is treated with strong acid at room temperature, isomerization occurs by the mechanism shown below to yield 1-isopropylcyclohexene:

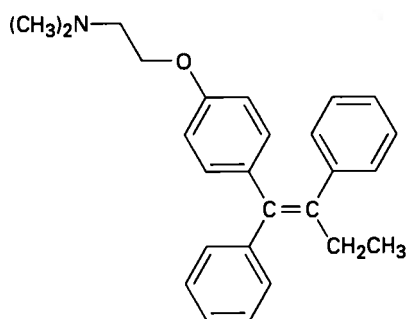


At equilibrium, the product mixture contains about 30% isopropylidenecyclohexane and about 70% 1-isopropylcyclohexene.

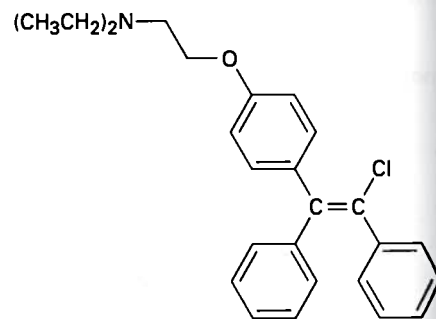
- (a) What kind of reaction is occurring? Is the mechanism polar or radical?
- (b) Draw curved arrows to indicate electron flow in each step.
- 3.60** We'll see in the next chapter that the stability of carbocations depends on the number of alkyl groups attached to the positively charged carbon—the more alkyl groups, the more stable the cation. Draw the two possible carbocation intermediates that might be formed in the reaction of HCl with 2-methylpropene (Problem 3.55), tell which is more stable, and predict which product will form.

IN THE MEDICINE CABINET

- 3.61** Tamoxifen and clomiphene have similar structures but very different medical uses. Tell whether the alkene double bond in each is *E* or *Z*.

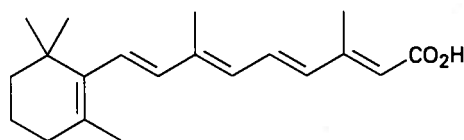


Tamoxifen
(antitumor agent)



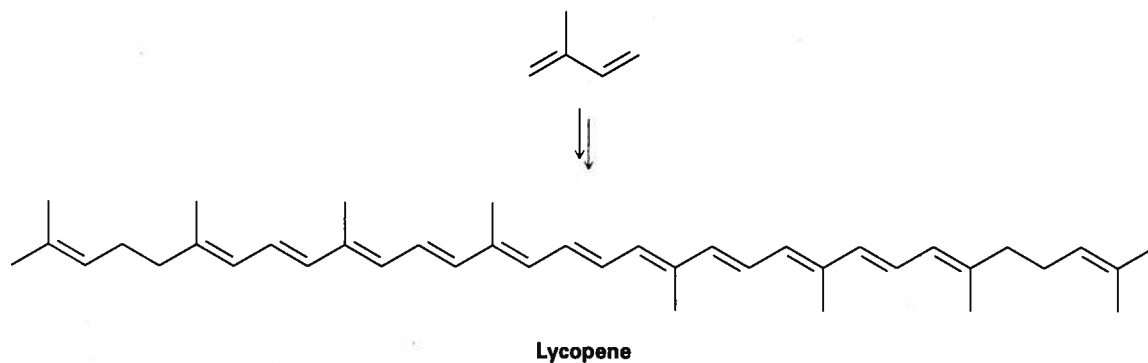
Clomiphene
(fertility treatment)

- 3.62** Retin A, or retinoic acid, is a medication commonly used to reduce wrinkles and treat severe acne. How many different isomers arising from double bond isomerizations are possible?



Retin A (retinoic acid)

IN THE FIELD 3.63 Lycopene, the pigment that gives tomatoes their red color, is a terpene derived formally by the joining together of numerous isoprene units (see the *Interlude* in this chapter). Start at one end of the molecule, and identify all the contiguous isoprene groupings.



between two contributing resonance forms. The only difference between **resonance forms** is in the location of double-bond and lone-pair electrons. The atoms remain in the same places in both structures.

Many simple alkenes undergo **polymerization** when treated with a radical catalyst. **Polymers** are large molecules built up by the repetitive bond together of many small **monomer** units.

Alkynes are hydrocarbons that contain a carbon-carbon triple bond. Much of the chemistry of alkynes is similar to that of alkenes. For example, alkynes react with 1 equivalent of HBr and HCl to yield **vinyllic** halides, and with 1 equivalent of Br₂ and Cl₂ to yield 1,2-dihalides. Alkynes can also be hydrated by reaction with aqueous sulfuric acid in the presence of mercuric sulfate catalyst. The reaction leads to an intermediate enol that immediately isomerizes to a ketone. Alkynes can be hydrogenated with the Lindlar catalyst to yield **cis** alkene. Terminal alkynes are weakly acidic and can be converted to **acetylide anions** by treatment with a strong base. Reaction of the acetylide anion with a primary alkyl halide then gives an internal alkyne.

Summary of Reactions

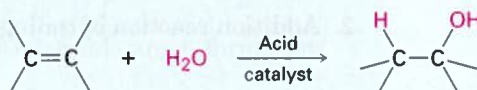
Note: No stereochemistry is implied unless specifically stated or indicated with wedged, solid, and dashed lines.

1. Reactions of alkenes

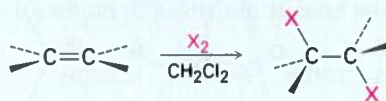
(a) Addition of HX, where X = Cl, Br, or I (Sections 4.1–4.2)



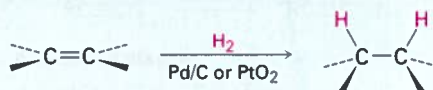
(b) Addition of H₂O (Section 4.3)



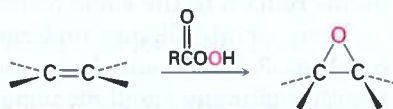
(c) Addition of X₂, where X = Cl, Br (Section 4.4)



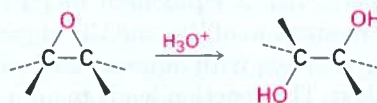
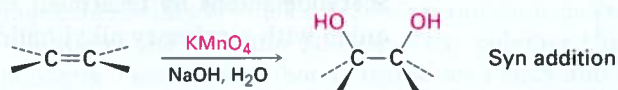
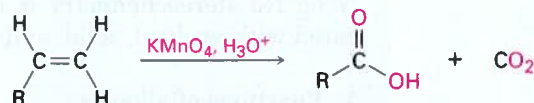
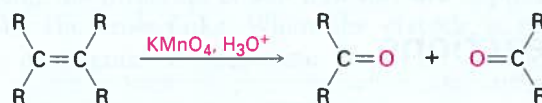
(d) Addition of H₂ (Section 4.5)



(e) Epoxidation (Section 4.6)



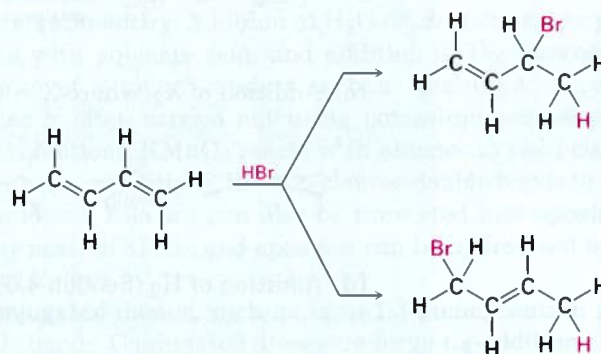
(f) Hydroxylation by acid-catalyzed epoxide hydrolysis (Section 4.6)

(g) Hydroxylation with KMnO_4 (Section 4.6)(h) Oxidative cleavage of alkenes with acidic KMnO_4 (Section 4.6)

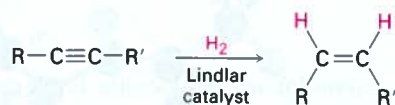
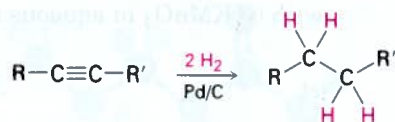
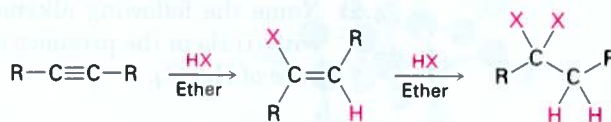
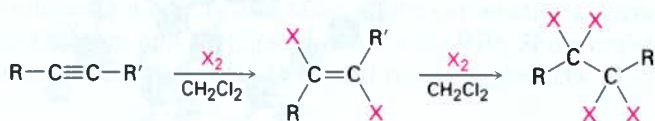
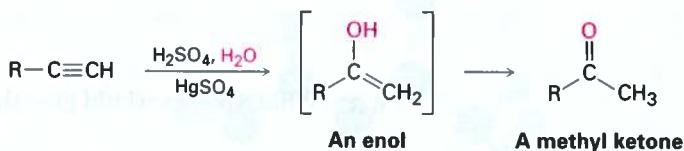
(i) Polymerization of alkenes (Section 4.7)



2. Addition reaction of conjugated dienes (Section 4.8)



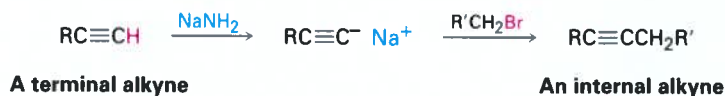
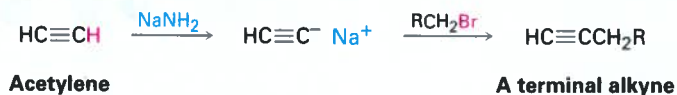
3. Reactions of alkynes (Section 4.11)

(a) Addition of H_2 **A cis alkene**(b) Addition of HX , where $X = Cl, Br$, or I (c) Addition of X_2 , where $X = Cl, Br$ (d) Addition of H_2O 

(e) Acetylide anion formation



(f) Reaction of acetylide anions with alkyl halides



Exercises

Visualizing Chemistry

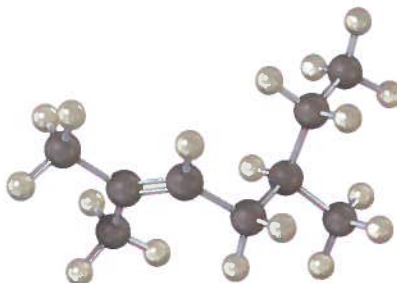
(Problems 4.1–4.20 appear within the chapter.)



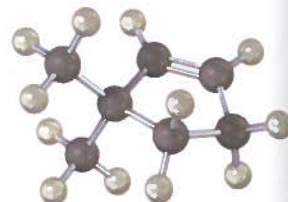
Interactive versions of these problems are assignable in OWL.

- 4.21** Name the following alkenes, and predict the products of their reaction with (i) KMnO_4 in aqueous acid and (ii) KMnO_4 in aqueous NaOH :

(a)



(b)

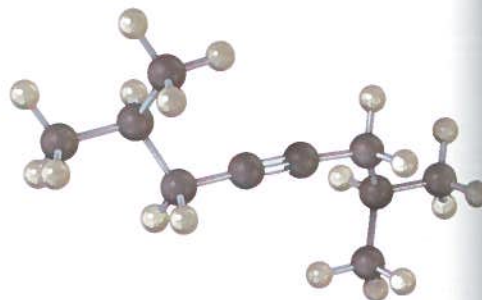


- 4.22** Name the following alkynes, and predict the products of their reaction with (i) H_2 in the presence of a Lindlar catalyst and (ii) H_3O^+ in the presence of HgSO_4 :

(a)

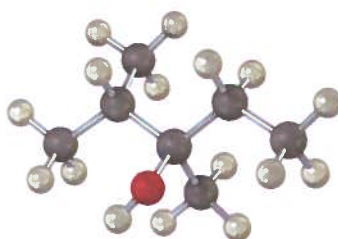


(b)

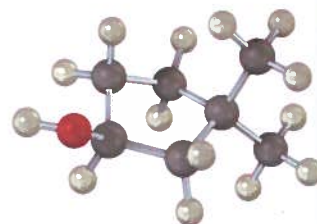


- 4.23** What alkenes would give the following alcohols on hydration? (Red = O).

(a)

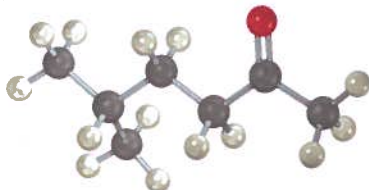


(b)

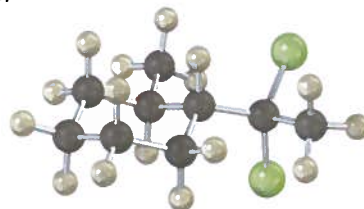


- 4.24 From what alkyne might each of the following substances have been made? (Red = O, yellow-green = Cl).

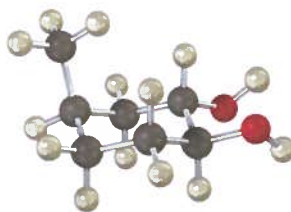
(a)



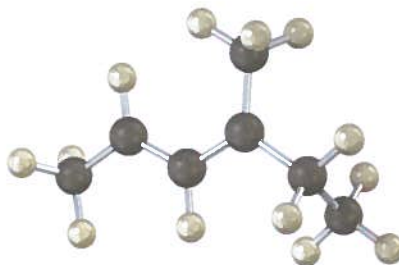
(b)



- 4.25 From what alkene was the following 1,2-diol made, and what method was used, epoxide hydrolysis or KMnO_4 in basic solution? (Red = O).



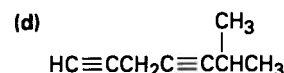
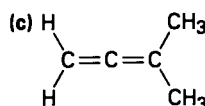
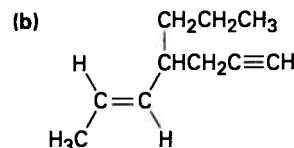
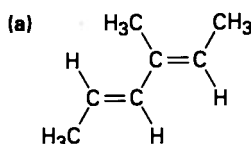
- 4.26 The following model is that of an allylic carbocation intermediate formed by protonation of a conjugated diene with HBr . Show the structure of the diene and the structures of the final reaction products.



Additional Problems

NAMING ALKENES
AND ALKYNES

4.27 Give IUPAC names for the following compounds:



4.28 Draw structures corresponding to the following IUPAC names:

- (a) 3-Ethylhept-1-yne (b) 3,5-Dimethylhex-4-en-1-yne
(c) Hepta-1,5-diyne (d) 1-Methylcyclopenta-1,3-diene

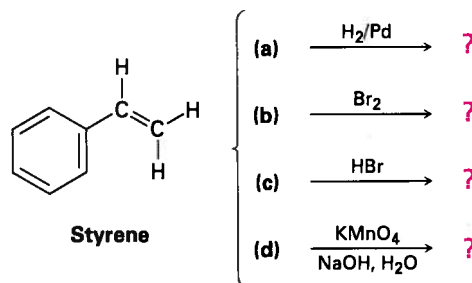
4.29 The following two hydrocarbons have been isolated from plants in the sunflower family. Name them according to IUPAC rules.

- (a) $\text{CH}_3\text{CH}=\text{CHC}\equiv\text{CC}\equiv\text{CCH}=\text{CHCH}=\text{CHCH}=\text{CH}_2$ (all trans)
(b) $\text{CH}_3\text{C}\equiv\text{CC}\equiv\text{CC}\equiv\text{CC}\equiv\text{CC}\equiv\text{CCH}=\text{CH}_2$

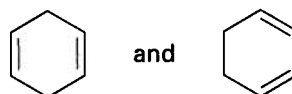
4.30 Draw and name all the possible pentyne isomers, C_5H_8 .4.31 Draw and name the six possible diene isomers of formula C_5H_8 . Which of the six are conjugated dienes?4.32 Draw three possible structures for each of the following formulas:
(a) C_6H_8 (b) $\text{C}_6\text{H}_8\text{O}$

PREDICT THE PRODUCTS

4.33 Predict the products of the following reactions. Indicate regioselectivity where relevant. (The aromatic ring is inert to all the indicated reagents.)



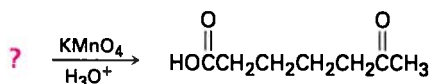
4.34 Using an oxidative cleavage reaction, explain how you would distinguish between the following two isomeric cyclohexadienes:



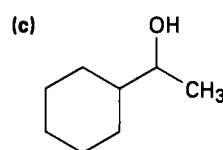
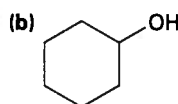
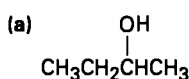
- 4.35 Formulate the reaction of cyclohexene with (i) Br_2 and (ii) *meta*-chloroperoxybenzoic acid followed by H_3O^+ . Show the reaction intermediates and the final products with correct cis or trans stereochemistry.
- 4.36 What products would you expect to obtain from reaction of cyclohexa-1,3-diene with each of the following?
 (a) 1 mol Br_2 in CH_2Cl_2 (b) 1 mol HCl
 (c) 1 mol DCI (D = deuterium, ^2H) (d) 2 mol H_2 over a Pd catalyst
- 4.37 Predict the products of the following reactions on hex-1-yne:
 (a) $\xrightarrow{1 \text{ equiv HBr}}$? (b) $\xrightarrow{1 \text{ equiv Cl}_2}$? (c) $\xrightarrow{\text{H}_2, \text{ Lindlar catalyst}}$?
- 4.38 Predict the products of the following reactions on dec-5-yne:
 (a) $\xrightarrow{\text{H}_2, \text{ Lindlar catalyst}}$? (b) $\xrightarrow{2 \text{ equiv Br}_2}$? (c) $\xrightarrow{\text{H}_2\text{O}, \text{ H}_2\text{SO}_4, \text{ HgSO}_4}$?
- 4.39 Suggest structures for alkenes that give the following reaction products. There may be more than one answer for some cases.
- (a) ? $\xrightarrow{\text{H}_2/\text{Pd catalyst}}$ 2-Methylhexane
- (b) ? $\xrightarrow{\text{Br}_2 \text{ in } \text{CH}_2\text{Cl}_2}$ 2,3-Dibromo-5-methylhexane
- (c) ? $\xrightarrow{\text{HBr}}$ 2-Bromo-3-methylheptane
- (d) ? $\xrightarrow[\text{H}_2\text{O}]{\text{KMnO}_4, \text{ OH}^-}$ $\begin{array}{ccccccc} & \text{CH}_3 & & \text{HO} & & \text{OH} & \\ & | & & | & & | & \\ \text{CH}_3 & \text{CH} & \text{CH}_2 & \text{CH} & \text{CH} & \text{CH}_2 & \text{CH}_3 \end{array}$

PREDICT THE REACTANTS

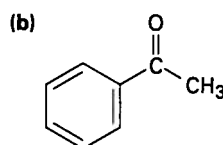
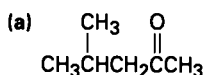
- 4.40 Draw the structure of a hydrocarbon that reacts with only 1 equivalent of H_2 on catalytic hydrogenation and gives only pentanoic acid, $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CO}_2\text{H}$, on treatment with acidic KMnO_4 . Write the reactions involved.
- 4.41 Give the structure of an alkene that yields the following keto acid on reaction with KMnO_4 in aqueous acid:



4.42 What alkenes would you hydrate to obtain the following alcohols?



4.43 What alkynes would you hydrate to obtain the following ketones?

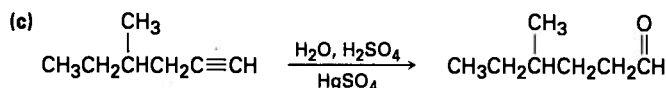
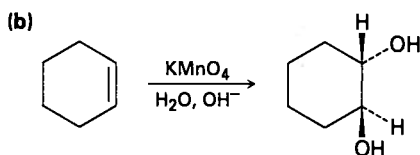
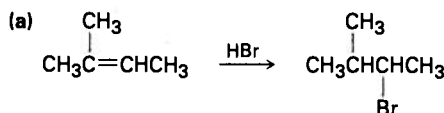


4.44 Draw the structure of a hydrocarbon that reacts with 2 equivalents of H_2 on catalytic hydrogenation and gives only succinic acid on reaction with acidic KMnO_4 .



SYNTHESIS

4.45 In planning the synthesis of a compound, it's as important to know what *not* to do as to know what to do. What is wrong with each of the following reactions?



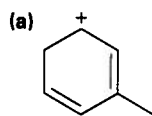
4.46 How would you prepare *cis*-but-2-ene starting from propyne, an alkyl halide, and any other reagents needed? (This problem can't be worked in a single step. You'll have to carry out more than one reaction.)

4.47 Using but-1-yne as the only organic starting material, along with any inorganic reagents needed, how would you synthesize the following compounds? (More than one step may be needed.)

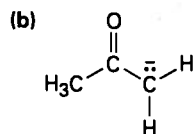
- (a) Butane (b) 1,1,2,2-Tetrachlorobutane
(c) 2-Bromobutane (d) Butan-2-one ($\text{CH}_3\text{CH}_2\text{COCH}_3$)

RESONANCE

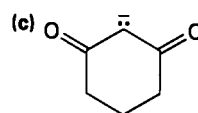
4.48 Draw the indicated number of additional resonance structures for each of the following substances:



(two)

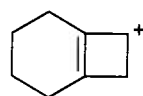
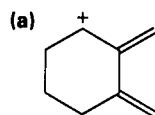


(one)

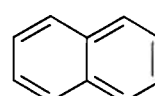
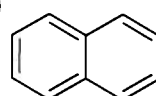


(two)

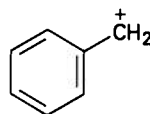
4.49 One of the following pairs of structures represents resonance forms, and one does not. Explain which is which.



(b)

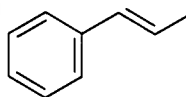


4.50 Draw three additional resonance structures for the benzyl cation.



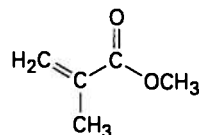
Benzyl cation

4.51 In light of your answer to Problem 4.50, what product would you expect from the following reaction? Explain.



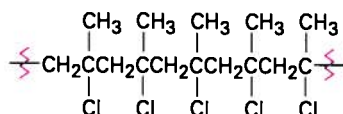
POLYMERS

4.52 Plexiglas, a clear plastic used to make many molded articles, is made by polymerization of methyl methacrylate. Draw a representative segment of Plexiglas.

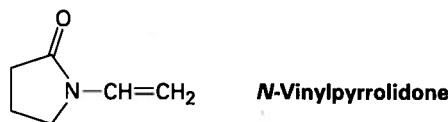


Methyl methacrylate

4.53 What monomer unit might be used to prepare the following polymer?

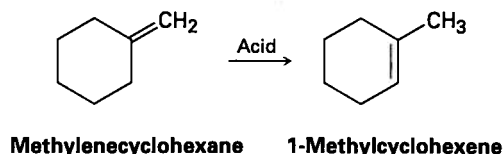


- 4.54 Poly(vinyl pyrrolidone), prepared by from *N*-vinylpyrrolidone, is used both in cosmetics and as a synthetic blood substitute. Draw a representative segment of the polymer.

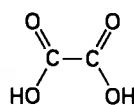


GENERAL PROBLEMS

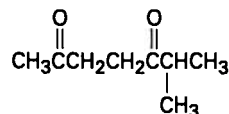
- 4.55 Reaction of 2-methylpropene with CH_3OH in the presence of H_2SO_4 catalyst yields methyl *tert*-butyl ether, $\text{CH}_3\text{OC}(\text{CH}_3)_3$, by a mechanism analogous to that of acid-catalyzed alkene hydration. Write the mechanism.
- 4.56 Compound **A** has the formula C_8H_8 . It reacts rapidly with acidic KMnO_4 but reacts with only 1 equivalent of H_2 over a palladium catalyst. On hydrogenation under conditions that reduce aromatic rings, **A** reacts with 4 equivalents of H_2 , and hydrocarbon **B**, C_8H_{16} , is produced. The reaction of **A** with KMnO_4 gives CO_2 and a carboxylic acid **C**, $\text{C}_7\text{H}_6\text{O}_2$. What are the structures of **A**, **B**, and **C**? Write all the reactions.
- 4.57 Compound **A**, C_9H_{12} , absorbs 3 equivalents of H_2 on catalytic reduction over a palladium catalyst to give **B**, C_9H_{18} . On reaction with KMnO_4 , compound **A** gives, among other things, a ketone that was identified as cyclohexanone. On treatment with NaNH_2 in NH_3 , followed by addition of iodomethane, compound **A** gives a new hydrocarbon **C**, $\text{C}_{10}\text{H}_{14}$. What are the structures of **A**, **B**, and **C**?
- 4.58 The sex attractant of the common housefly is a hydrocarbon named *muscalure*, $\text{C}_{23}\text{H}_{46}$. On treatment of muscalure with aqueous acidic KMnO_4 , two products are obtained, $\text{CH}_3(\text{CH}_2)_{12}\text{CO}_2\text{H}$ and $\text{CH}_3(\text{CH}_2)_7\text{CO}_2\text{H}$. Propose a structure for muscalure.
- 4.59 How would you synthesize muscalure (Problem 4.58) starting from acetylene and any alkyl halides needed? (The double bond in muscalure is *cis*.)
- 4.60 Draw an energy diagram for the addition of HBr to pent-1-ene. Let one curve on your diagram show the formation of 1-bromopentane product and another curve on the same diagram show the formation of 2-bromopentane product. Label the positions for all reactants, intermediates, and products.
- 4.61 Make sketches of what you imagine the transition-state structures to look like in the reaction of HBr with pent-1-ene (Problem 4.60).
- 4.62 Methylenecyclohexane, on treatment with strong acid, isomerizes to yield 1-methylcyclohexene. Propose a mechanism by which the reaction might occur.



- 4.63** α -Terpinene, $C_{10}H_{16}$, is a pleasant-smelling hydrocarbon that has been isolated from oil of marjoram. On hydrogenation over a palladium catalyst, α -terpinene reacts with 2 mol equiv of hydrogen to yield a new hydrocarbon, $C_{10}H_{20}$. On reaction with acidic $KMnO_4$, α -terpinene yields oxalic acid and 6-methylheptane-2,5-dione. Propose a structure for α -terpinene.

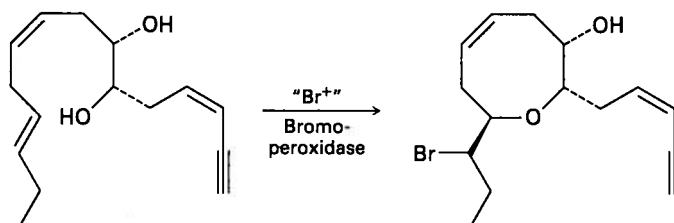


Oxalic acid



6-Methylheptane-2,5-dione

- 4.64** Prelaureatin, a substance isolated from marine algae, is thought to arise from laurediol by the following route. Propose a mechanism.



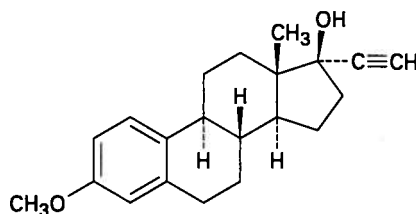
Laurediol

Prelaureatin

- 4.65** Hydroxylation of *cis*-but-2-ene with basic $KMnO_4$ yields a different product than hydroxylation of *trans*-but-2-ene. Draw the structure, show the stereochemistry of each product, and explain the result. We'll explore the stereochemistry of the products in more detail in Chapter 6.

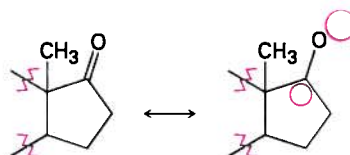
IN THE MEDICINE CABINET

- 4.66** The oral contraceptive agent Mestranol is synthesized by addition of acetylide ion to a carbonyl group.



Mestranol

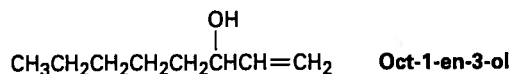
- (a) To understand the acetylide-addition reaction, first draw a resonance structure of the $C=O$ double bond based on electronegativity values, indicating where the $+$ and $-$ charges belong in the circles on the following abbreviated structure:



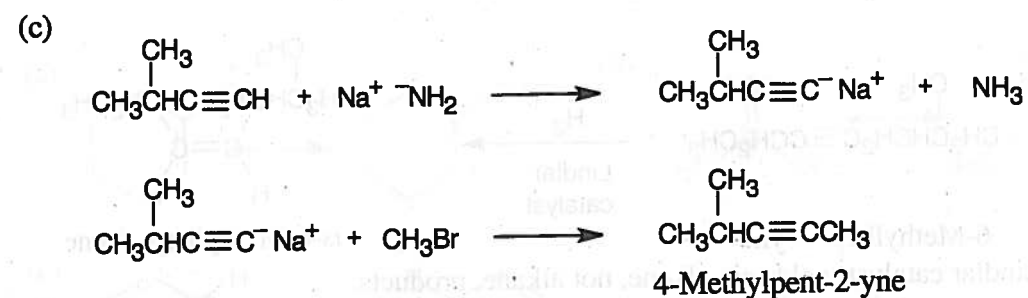
- (b) Then draw a two-step mechanism for the addition of acetylide ion to this resonance structure and subsequent protonation of the intermediate with acid.

IN THE FIELD

- 4.67 Oct-1-en-3-ol, a potent mosquito attractant commonly used in mosquito traps, can be prepared in two steps from hexanal, $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CHO}$. The first step is an acetylide-addition reaction like that described in Problem 4.66. What is the structure of the product from the first step, and how can it be converted into oct-1-en-3-ol?



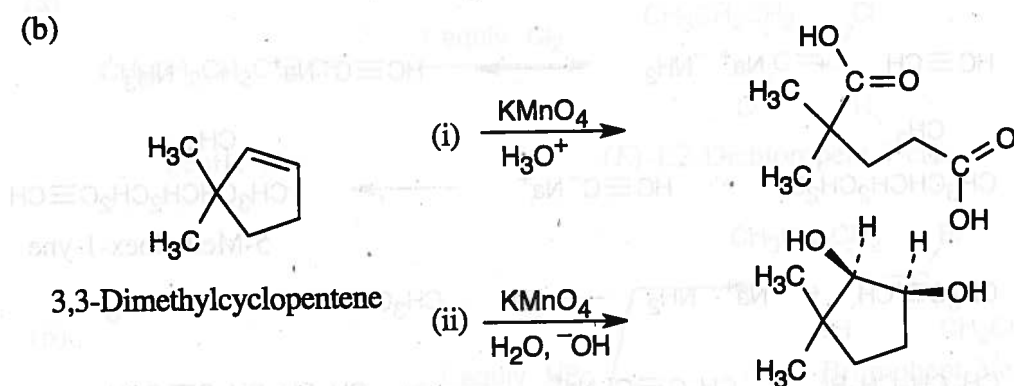
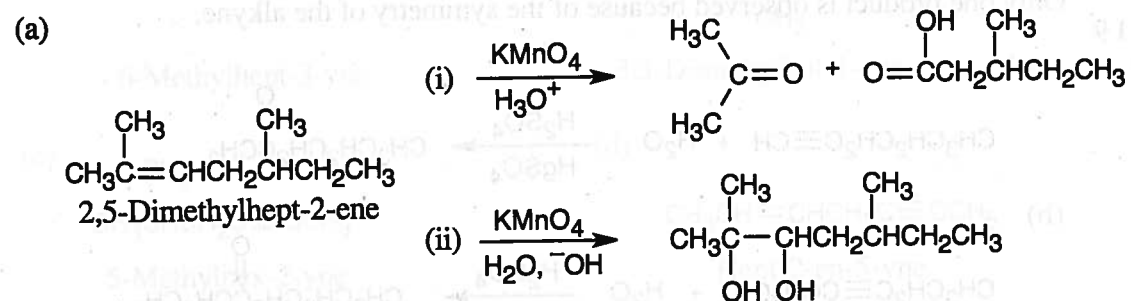
- 4.68 As we saw in the *Interlude* at the end of this chapter, natural rubber is a polymer of 2-methylbuta-1,3-diene that contains *Z* double bonds. Synthetic rubber, by contrast, is similar to natural rubber but contains *E* double bonds. Draw the structure of a representative section of synthetic rubber.



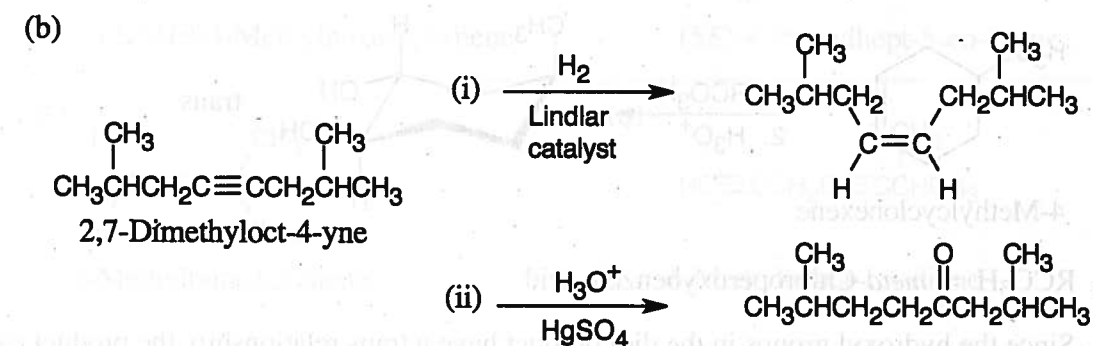
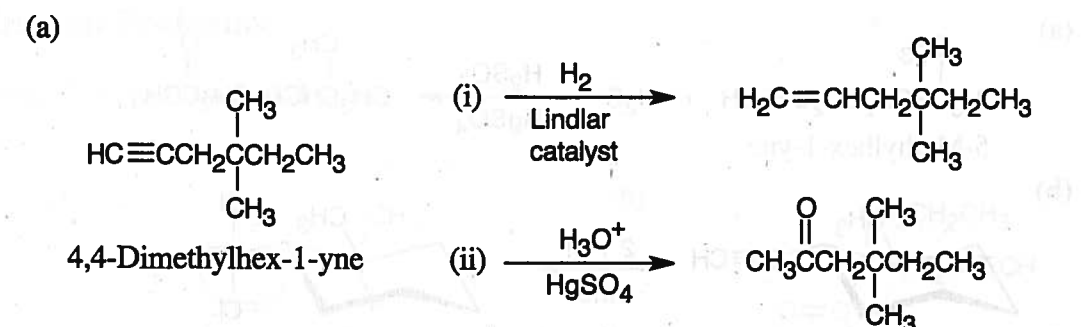
Note: The reaction of $\text{CH}_3\text{C}\equiv\text{C}^- \text{Na}^+$ with $(\text{CH}_3)_2\text{CHBr}$ doesn't yield the desired product because $(\text{CH}_3)_2\text{CHBr}$ is not a primary alkyl halide.

Visualizing Chemistry

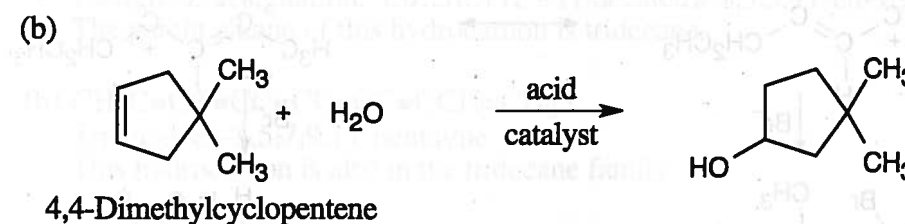
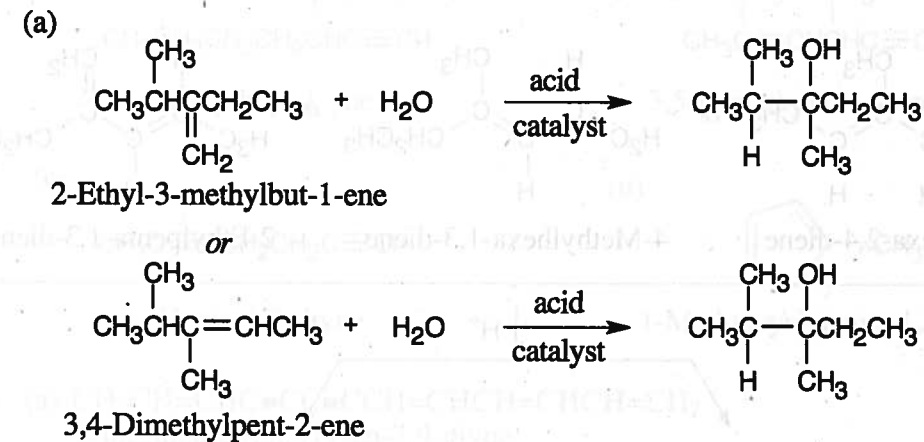
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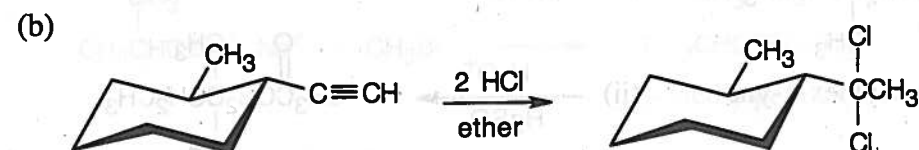
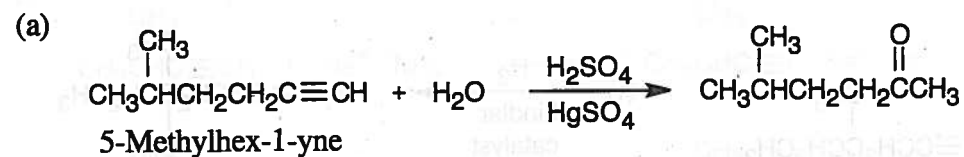
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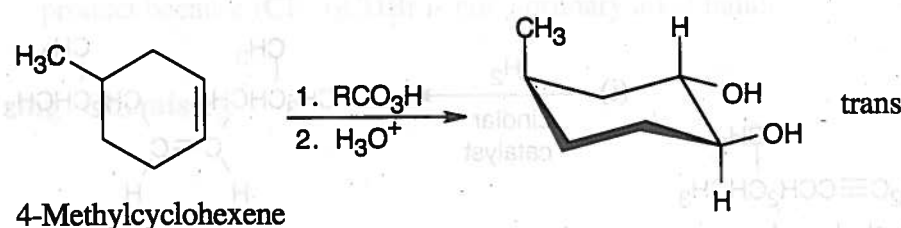
4.23



4.24



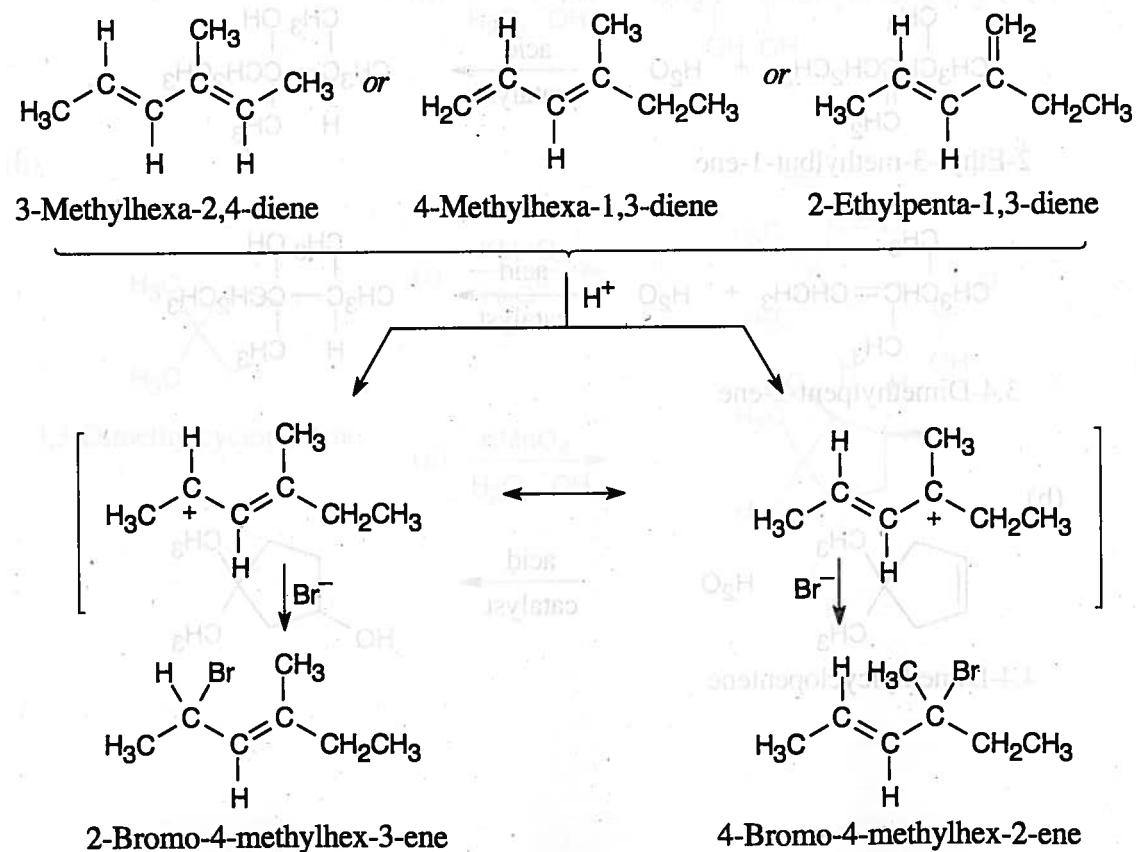
4.25



RCO_3H = *meta*-Chloroperoxybenzoic acid

Since the hydroxyl groups in the diol product have a *trans* relationship, the product can only be formed by epoxide hydrolysis. (Treatment of the alkene with KMnO_4 yields a product in which the two $-\text{OH}$ groups have a *cis* relationship.)

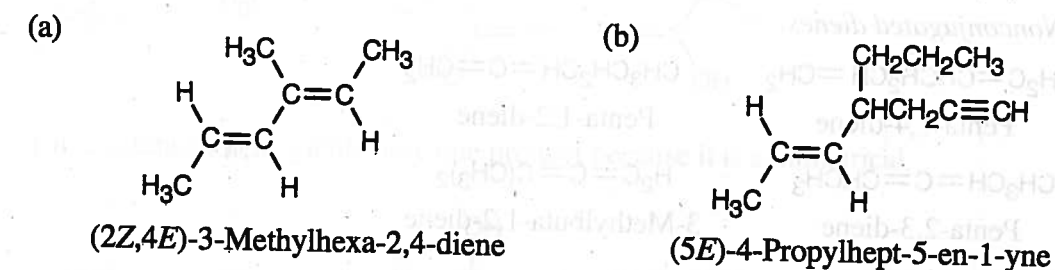
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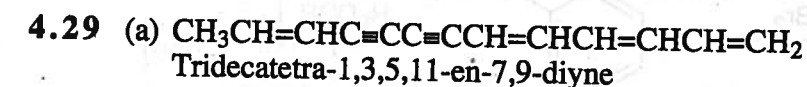
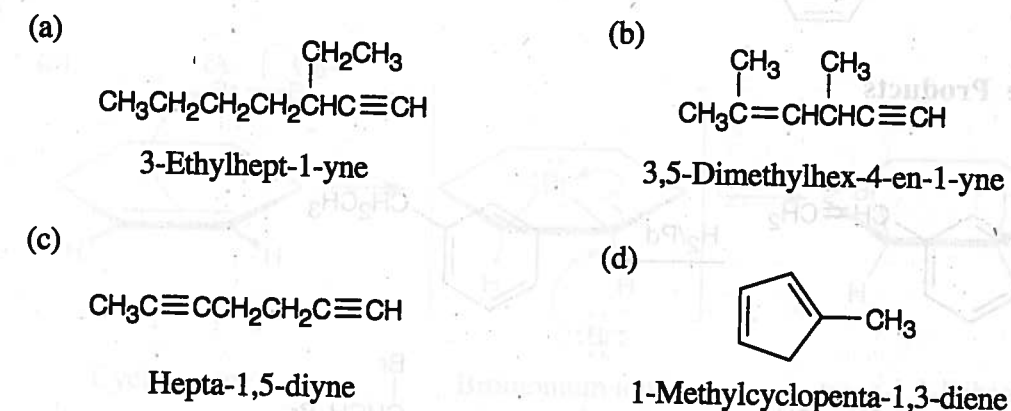
Additional Problems

Naming Alkenes and Alkynes

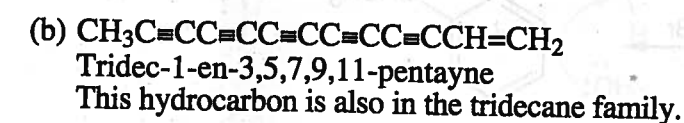
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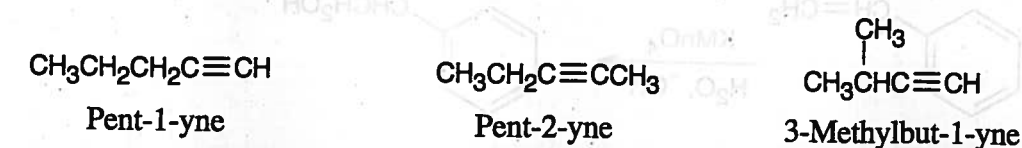
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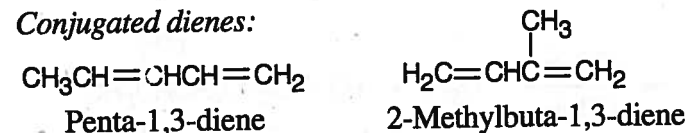
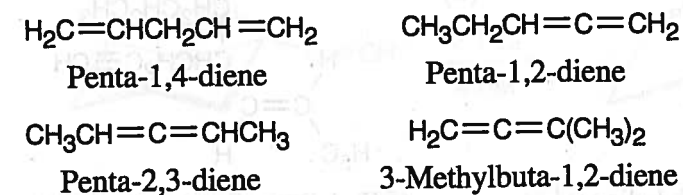
Using *E-Z* designation: (3*E*,5*E*,11*E*)-Tridecatetra-1,3,5,11-en-7,9-diyne
 The parent alkane of this hydrocarbon is tridecane.



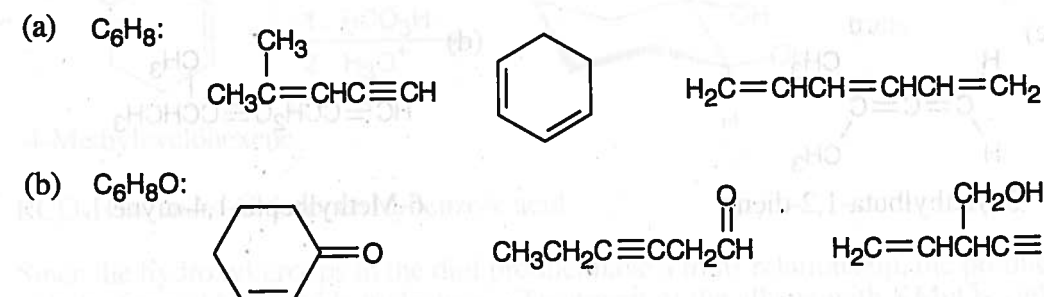
4.30



4.31

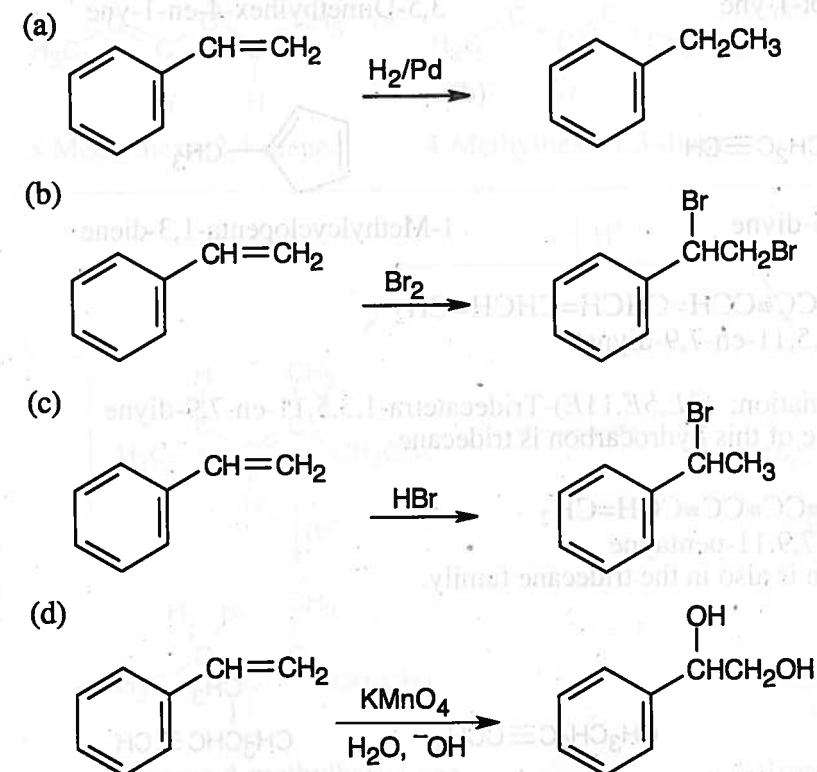
Conjugated dienes:*Nonconjugated dienes:*

4.32

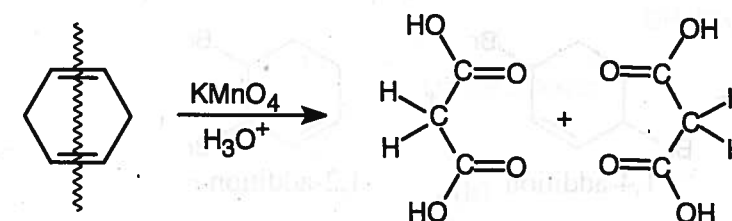


Predict the Products

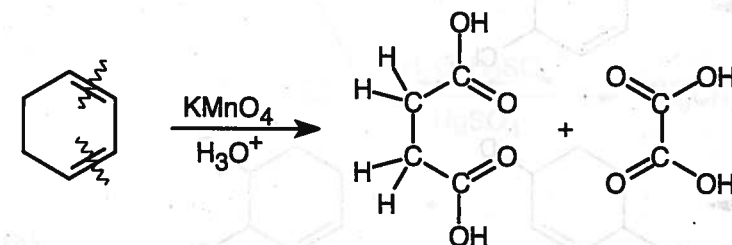
4.33



4.34

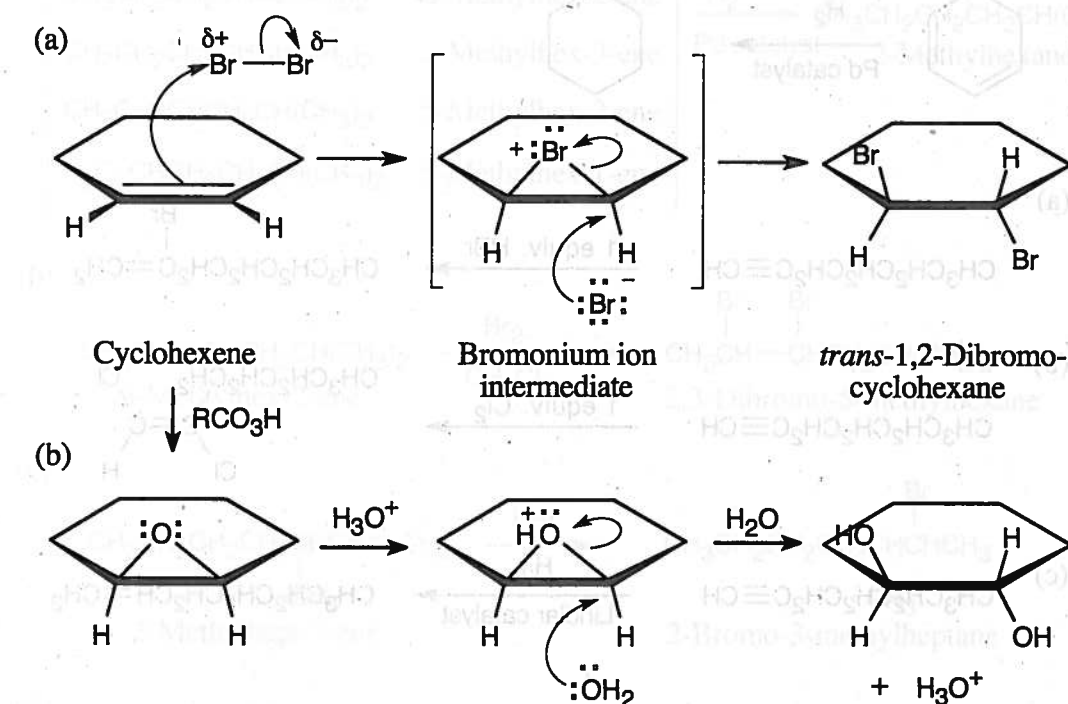


This cyclohexadiene yields only one product because it is symmetrical.

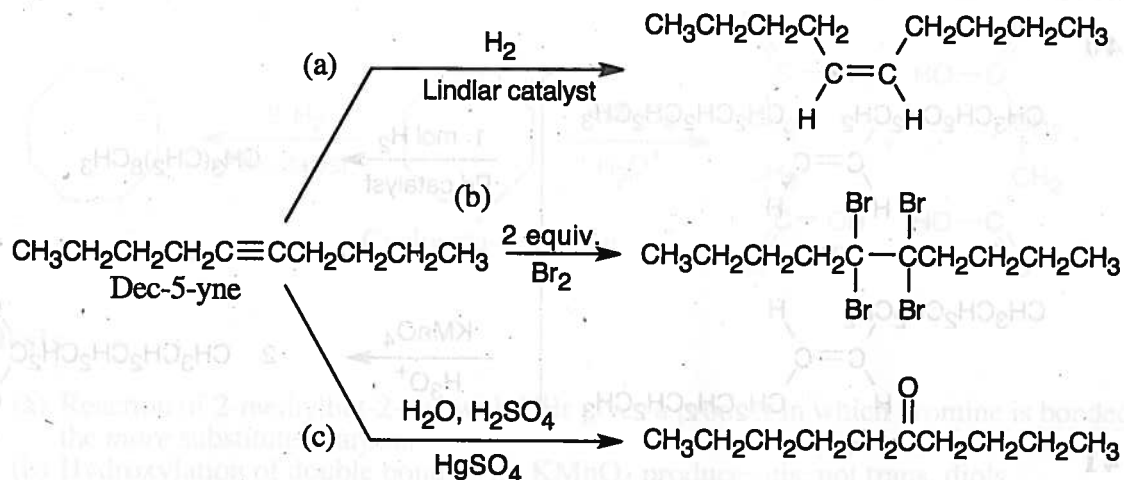


Two different products result from oxidative cleavage of this diene.

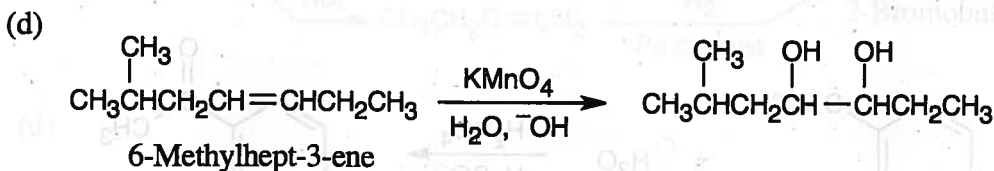
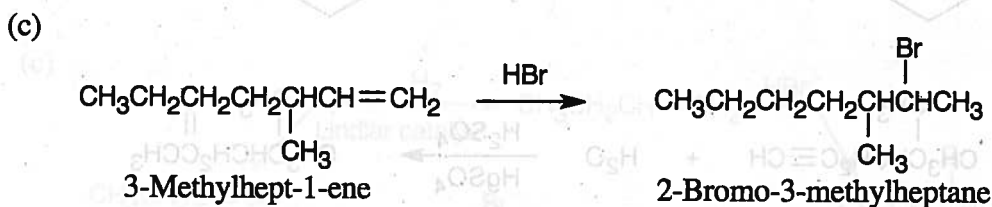
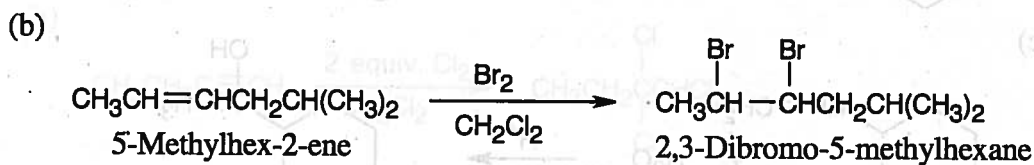
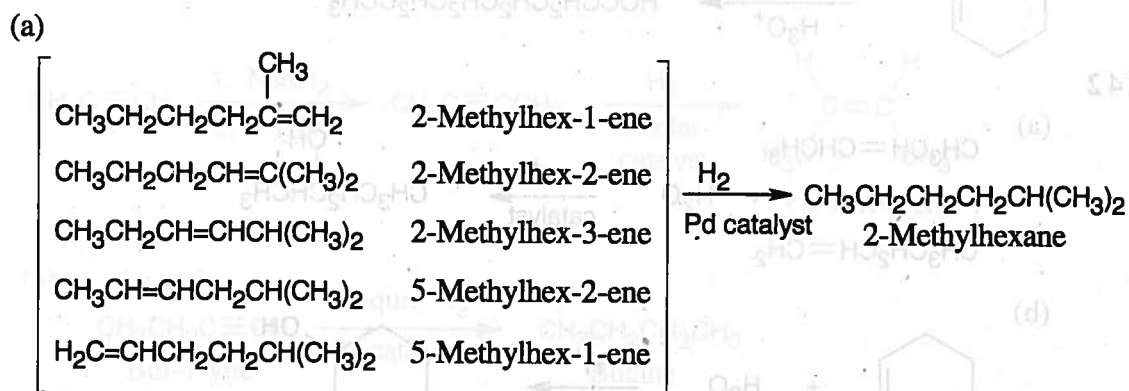
4.35



4.38

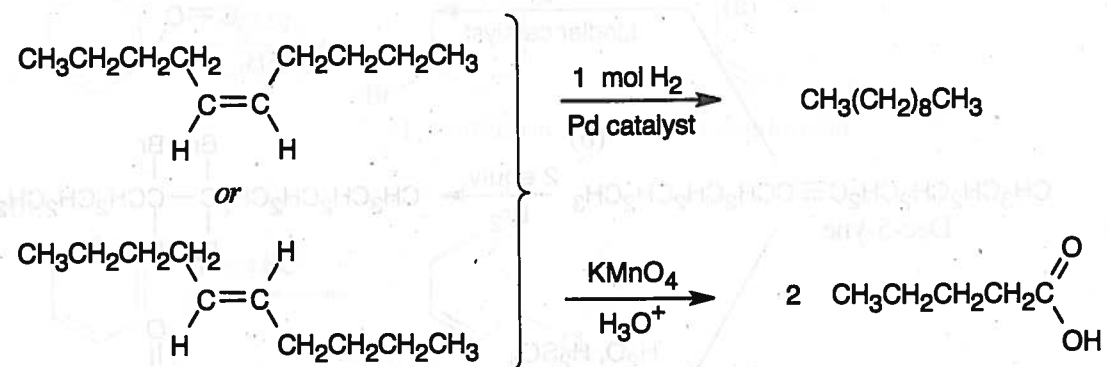


4.39

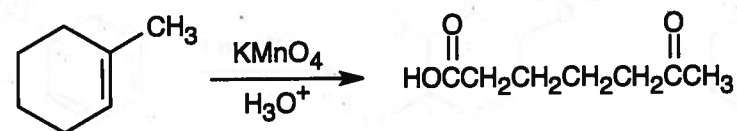


Predict the Reactants

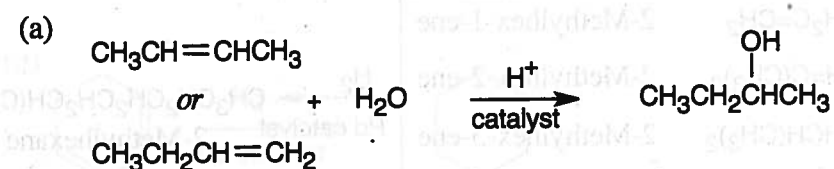
4.40



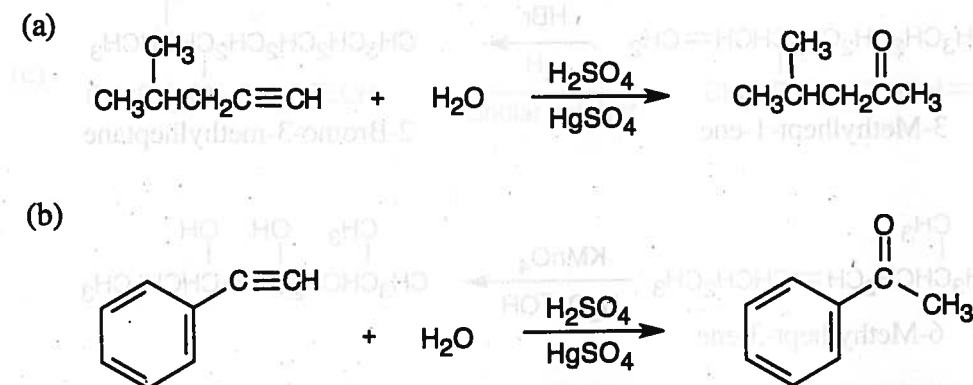
4.41



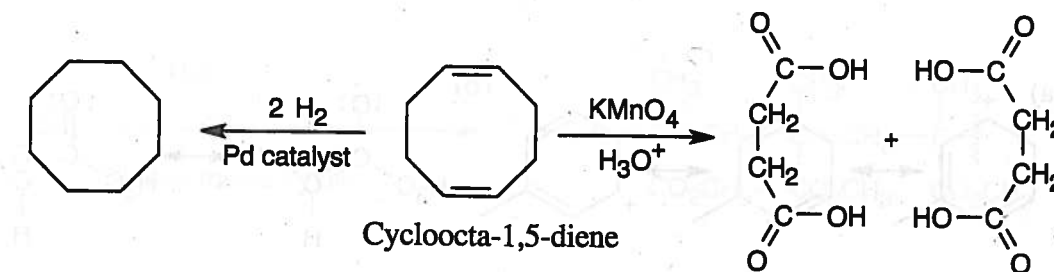
4.42



4.43



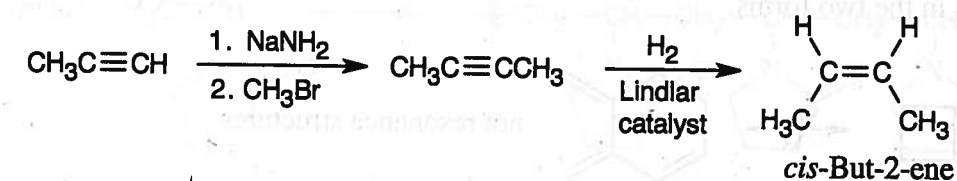
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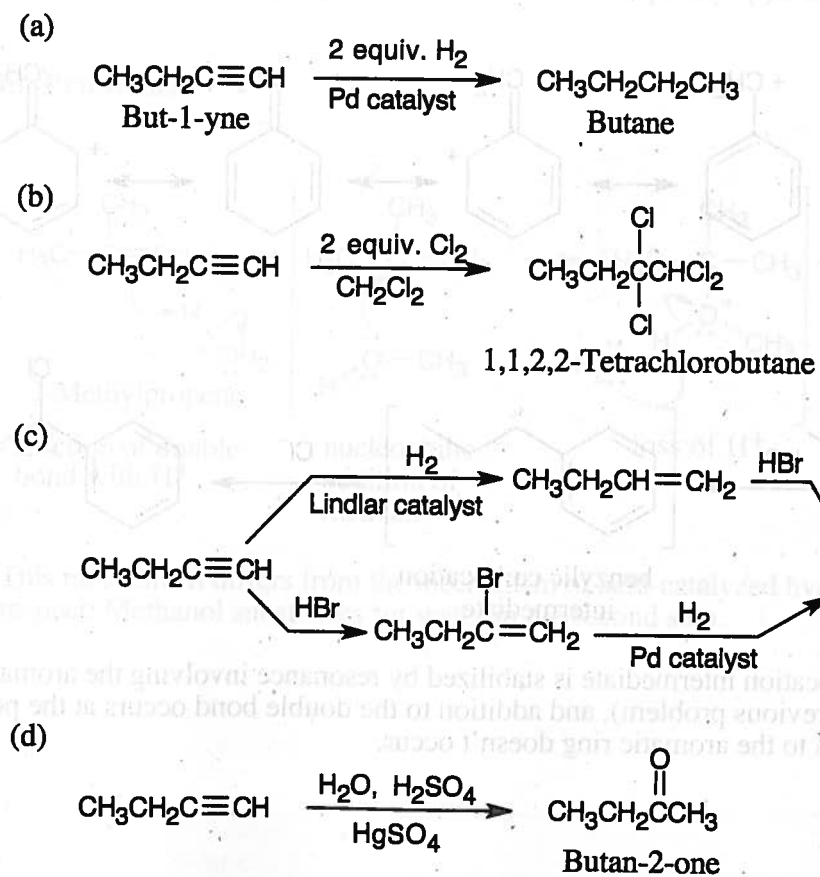
Synthesis

- 4.45 (a) Reaction of 2-methylbut-2-ene with HBr gives a product in which bromine is bonded to the *more* substituted carbon.
 (b) Hydroxylation of double bonds with KMnO₄ produces *cis*, not *trans*, diols.
 (c) Hydration of a terminal alkyne produces a ketone, not an aldehyde.

4.46

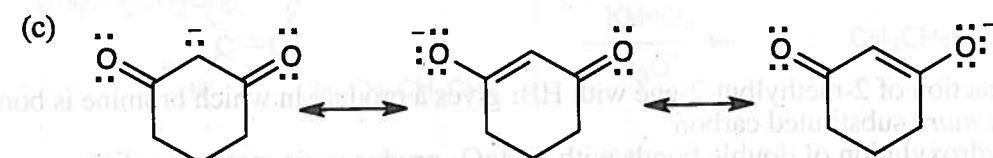
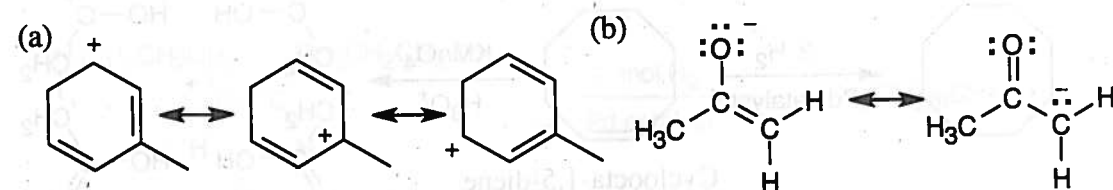


4.47

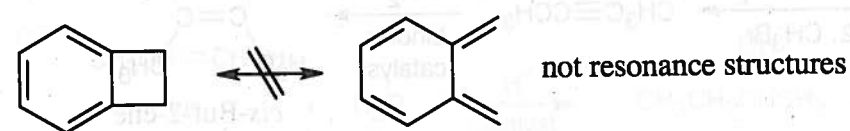


Resonance

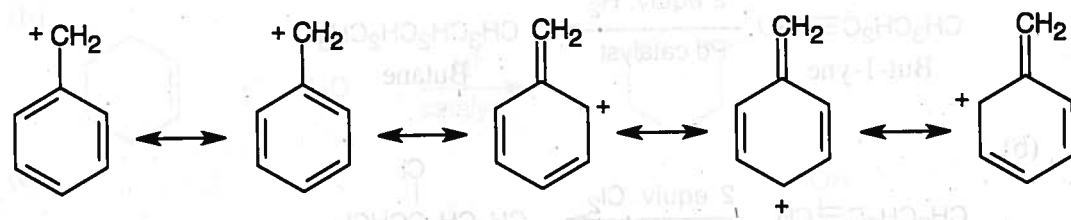
4.48



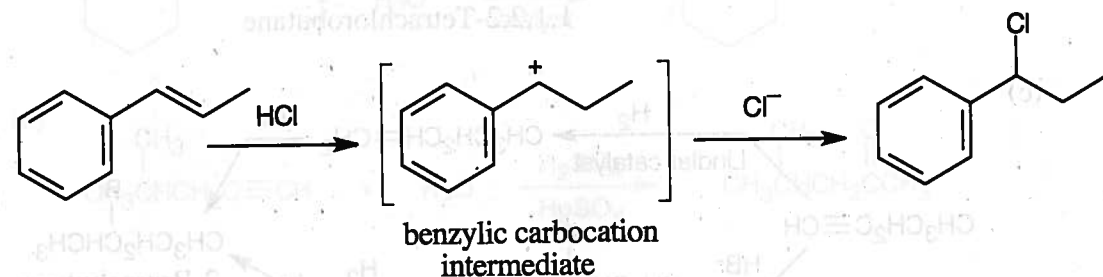
4.49 Resonance forms can't differ in the position of nuclei. The two structures in (a) are not resonance forms because the carbon and hydrogen atoms outside the ring occupy different positions in the two forms.



4.50



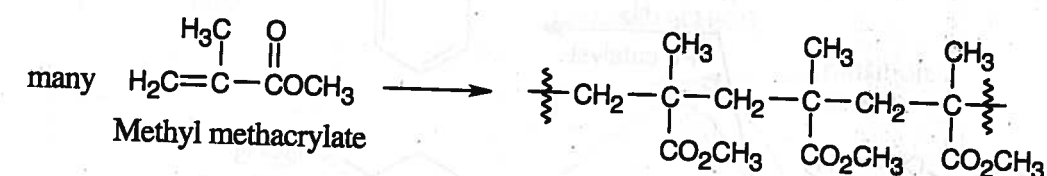
4.51



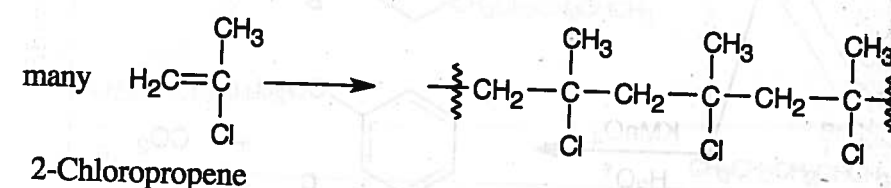
The benzylic carbocation intermediate is stabilized by resonance involving the aromatic ring (as shown in the previous problem), and addition to the double bond occurs at the position indicated. Addition to the aromatic ring doesn't occur.

Polymers

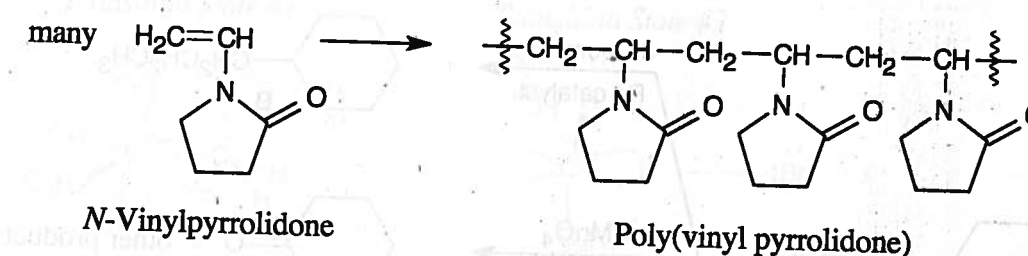
4.52



4.53

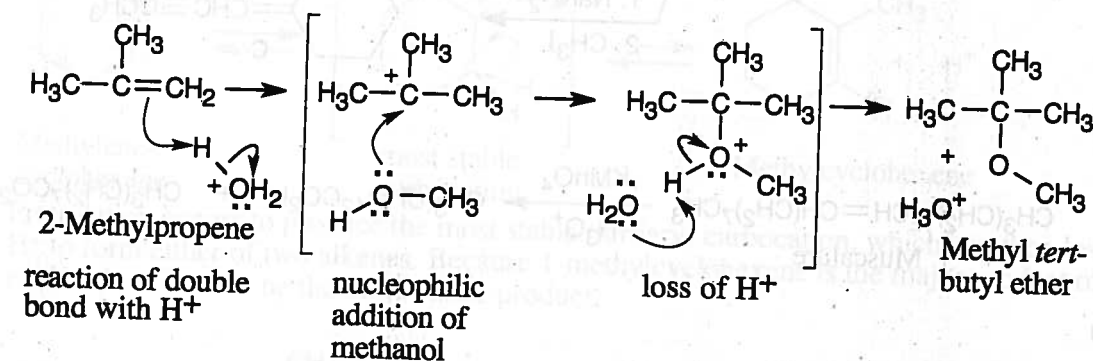


4.54



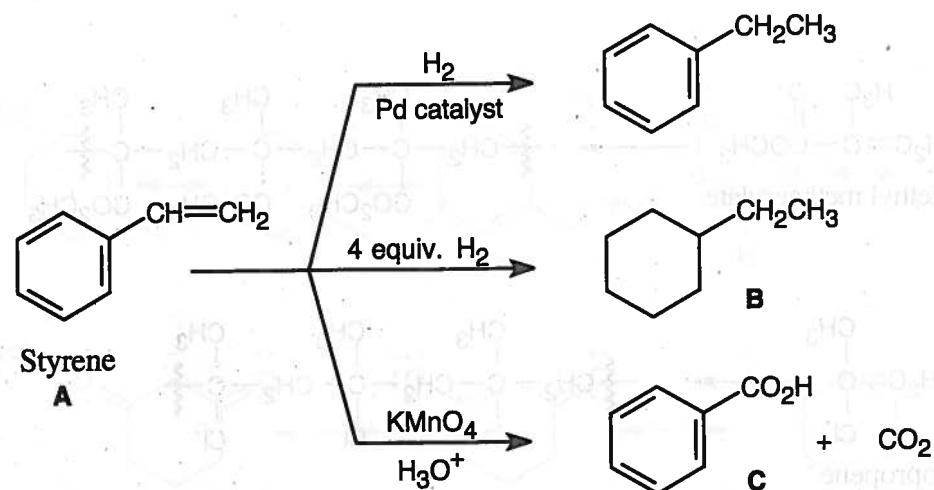
General Problems

4.55

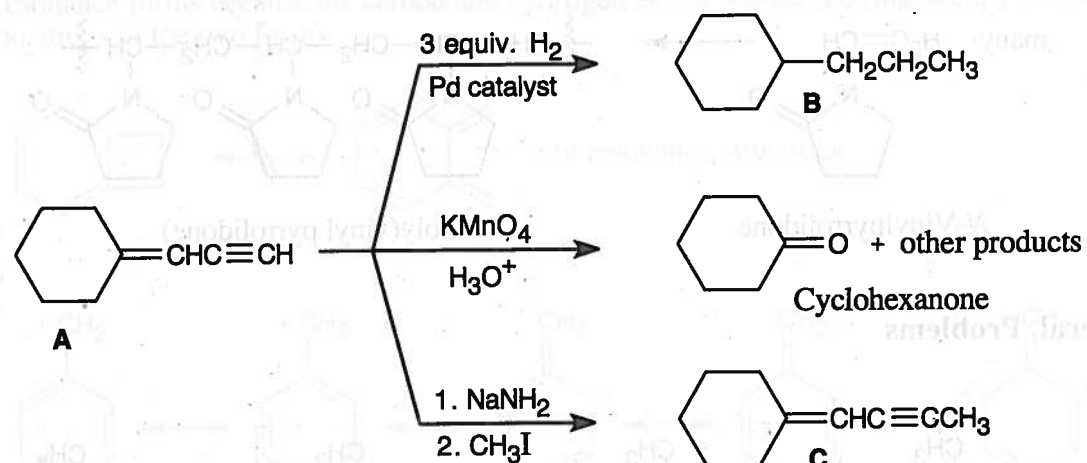


This mechanism differs from the mechanism of acid-catalyzed hydration in only one respect: Methanol substitutes for water in the second step.

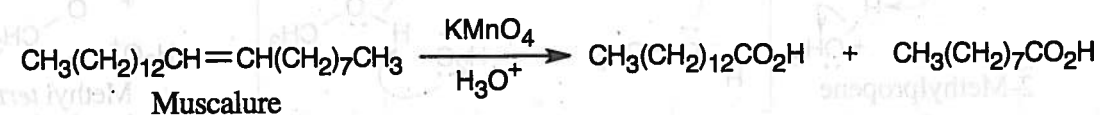
4.56



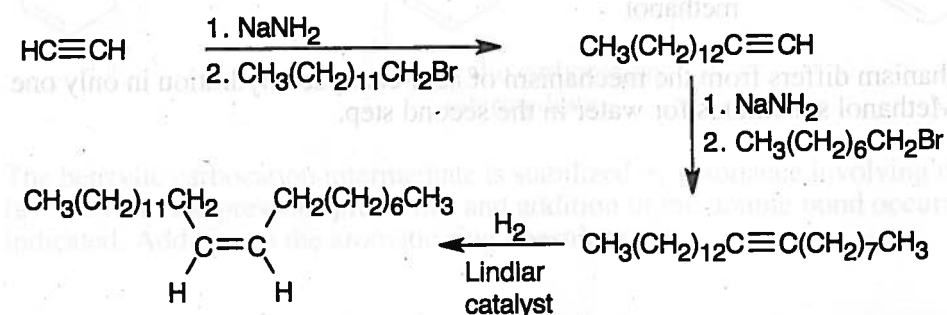
4.57



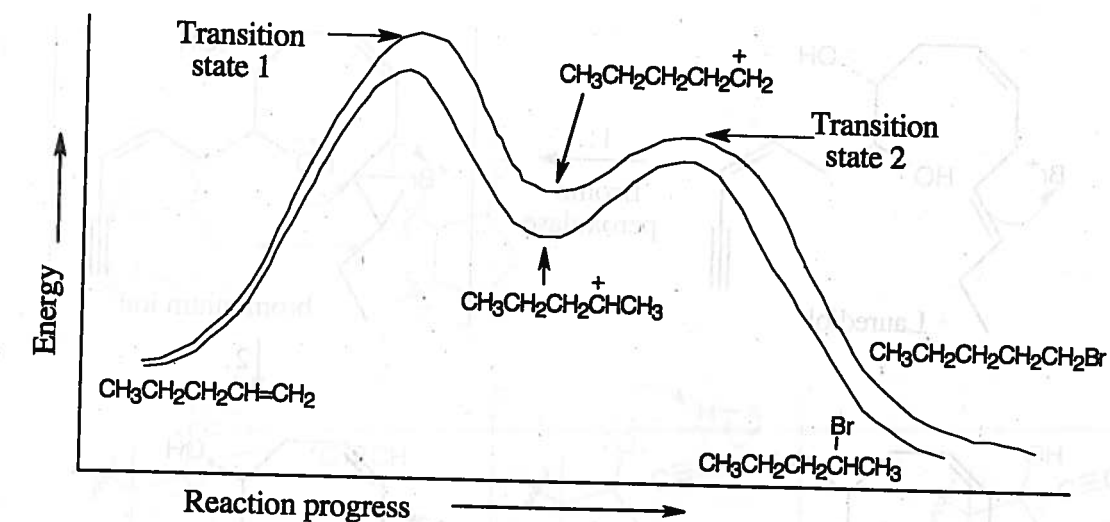
4.58



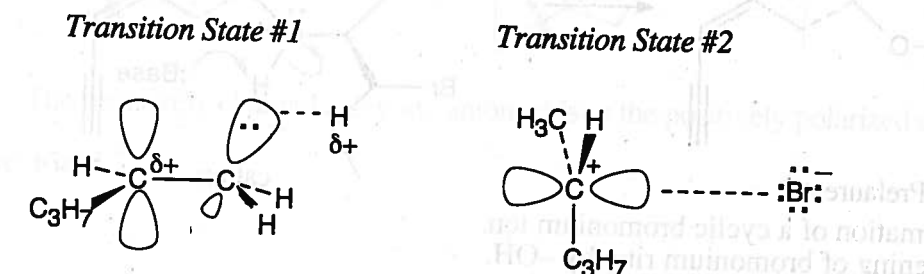
4.59



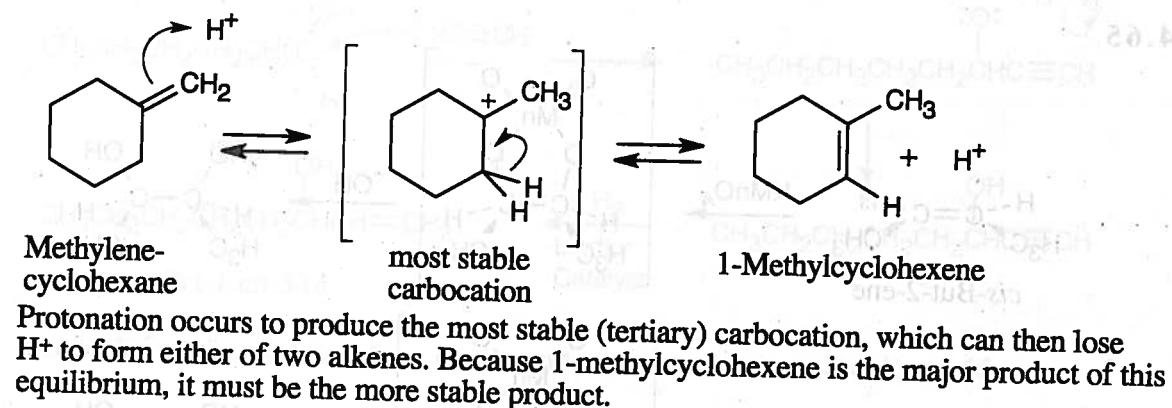
4.60



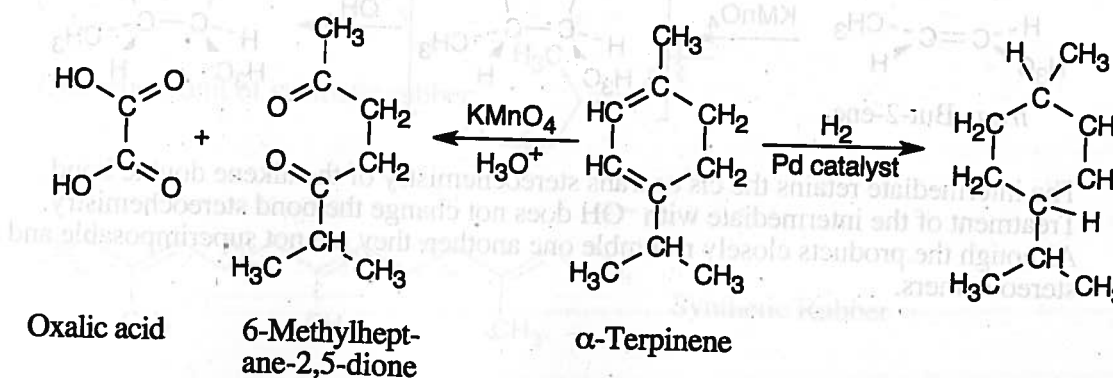
4.61



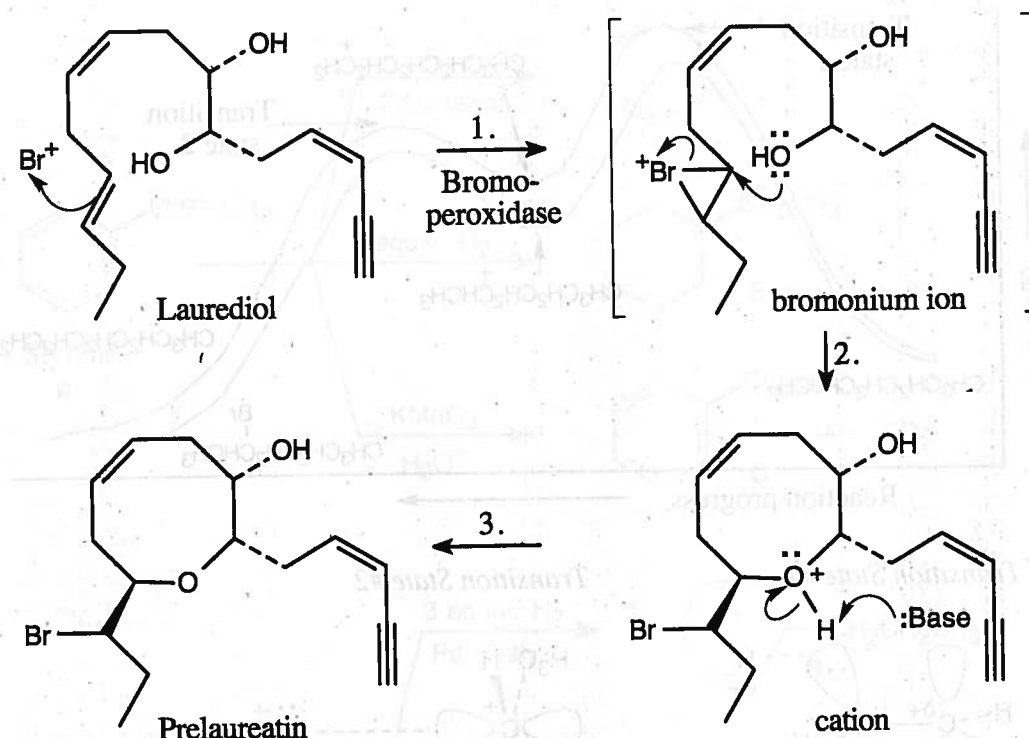
4.62



4.63

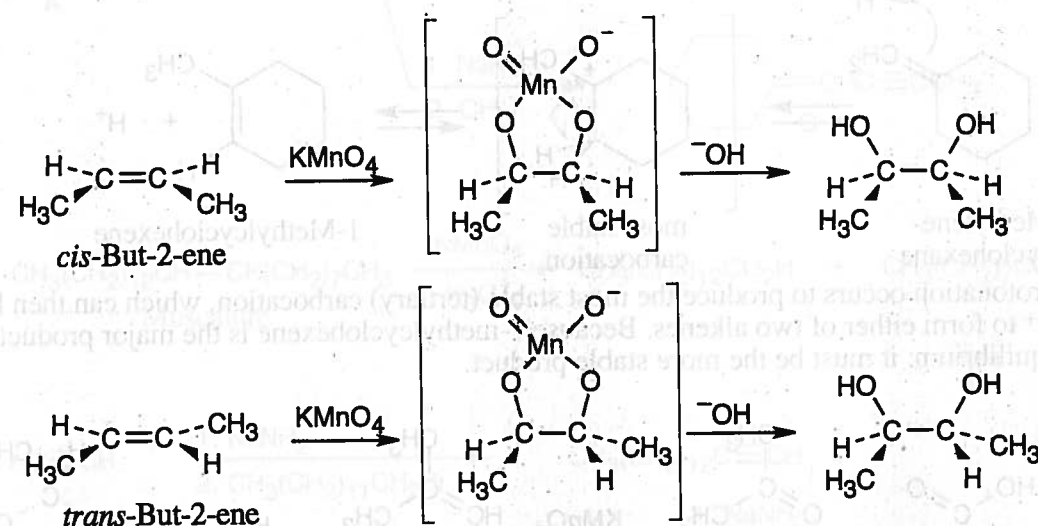


4.64



Step 1: Formation of a cyclic bromonium ion.
Step 2: Opening of bromonium ring by -OH .
Step 3: Removal of proton.

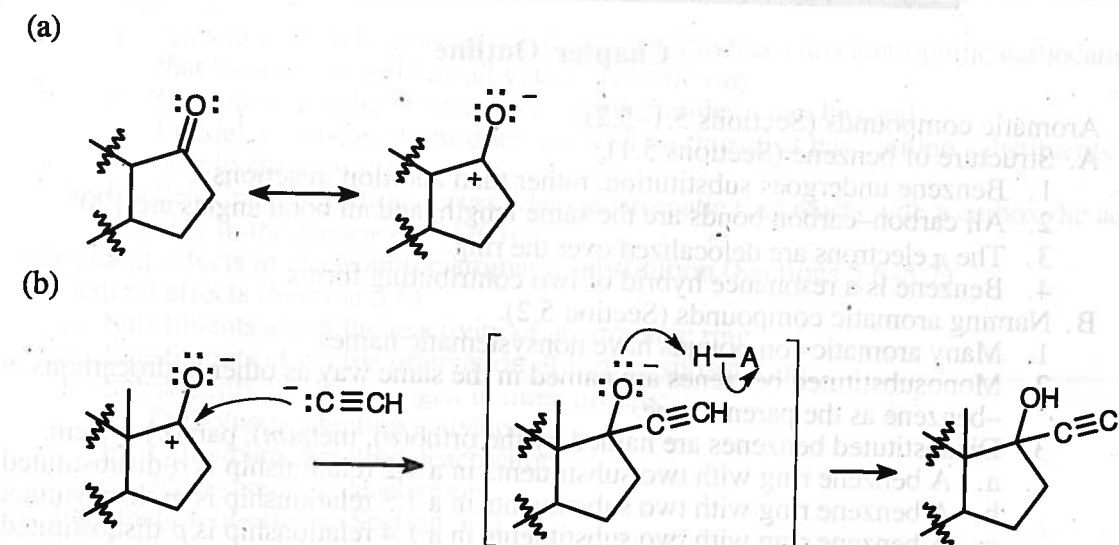
4.65



The intermediate retains the *cis* or *trans* stereochemistry of the alkene double bond. Treatment of the intermediate with -OH does not change the bond stereochemistry. Although the products closely resemble one another, they are not superimposable and are stereoisomers.

In the Medicine Cabinet

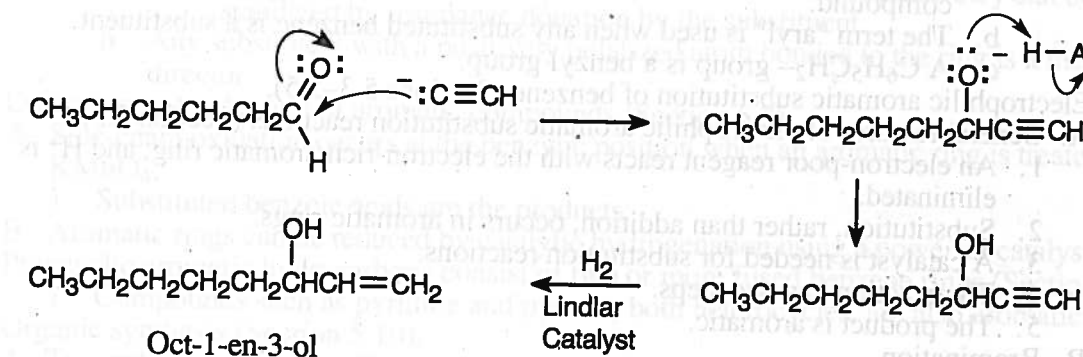
4.66



The negatively charged acetylide anion adds to the positively polarized carbon.

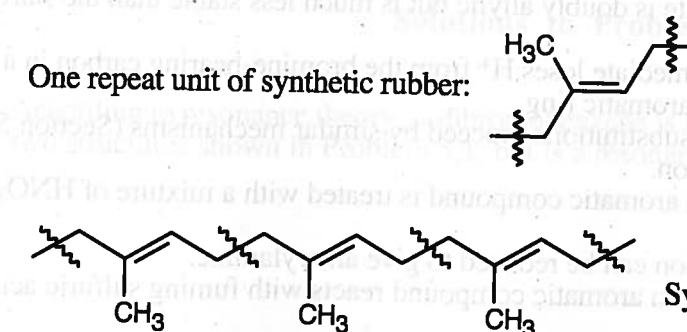
In the Field

4.67

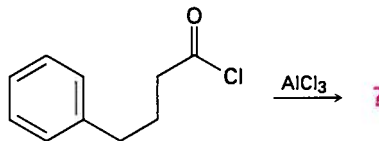


The addition of acetylide occurs by the same route as shown in Problem 4.66.

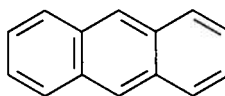
4.68



- 5.36** Rank the compounds in each group according to their reactivity toward electrophilic substitution:
- (a) Chlorobenzene, *o*-dichlorobenzene, benzene
 - (b) *p*-Bromonitrobenzene, nitrobenzene, phenol
 - (c) Fluorobenzene, benzaldehyde, *o*-dimethylbenzene
- 5.37** The orientation of electrophilic aromatic substitution on a disubstituted benzene ring is usually controlled by whichever of the two groups already on the ring is the more powerful activator. Name and draw the structure(s) of the major product(s) of electrophilic chlorination of the following substances:
- (a) *m*-Nitrophenol (b) *o*-Methylphenol (c) *p*-Chloronitrobenzene
- 5.38** Predict the major product(s) you would expect to obtain from sulfonation of the following substances (see Problem 5.37):
- (a) *o*-Chlorotoluene (b) *m*-Bromophenol (c) *p*-Nitrotoluene
- 5.39** Rank the following aromatic compounds in the expected order of their reactivity toward Friedel–Crafts acylation. Which compounds are unreactive?
- (a) Bromobenzene
 - (b) Toluene
 - (c) Anisole ($\text{C}_6\text{H}_5\text{OCH}_3$)
 - (d) Nitrobenzene
 - (e) *p*-Bromotoluene
- 5.40** In some cases, the Friedel–Crafts acylation reaction can occur *intramolecularly*, that is, within the same molecule. Predict the product of the following reaction:



- 5.41** What is the structure of the compound with formula $\text{C}_8\text{H}_9\text{Br}$ that gives *p*-bromobenzoic acid on oxidation with KMnO_4 ?
- 5.42** Draw the three additional resonance structures of anthracene.



Anthracene

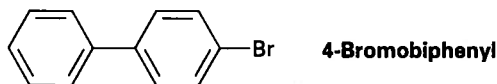
MECHANISMS

- 5.43** Show the steps involved in the Friedel–Crafts reaction of benzene with CH_3Cl .
- 5.44** Propose a mechanism to explain the fact that deuterium (D , ^2H) slowly replaces hydrogen (^1H) in the aromatic ring when benzene is treated with D_2SO_4 .

- 5.45 Use resonance structures of the possible carbocation intermediates to explain why bromination of biphenyl occurs at the ortho and para positions rather than at the meta positions.

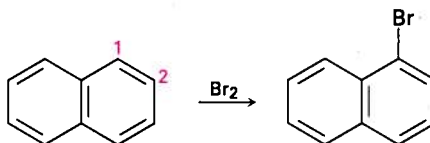


- 5.46 In light of your answer to Problem 5.45, at what position and on which ring would you expect nitration of 4-bromobiphenyl to occur?



SYNTHESIS

- 5.47 Starting with benzene, how would you synthesize the following substances? Assume that you can separate ortho and para isomers if necessary.
 (a) *m*-Bromobenzenesulfonic acid (b) *o*-Chlorobenzenesulfonic acid
 (c) *p*-Chlorotoluene
- 5.48 Starting from any aromatic hydrocarbon of your choice, how would you synthesize the following substances? Ortho and para isomers can be separated if necessary.
 (a) *o*-Nitrobenzoic acid (b) *p*-*tert*-Butylbenzoic acid
- 5.49 Explain by drawing resonance structures of the intermediate carbocations why naphthalene undergoes electrophilic aromatic substitution at C1 rather than at C2.

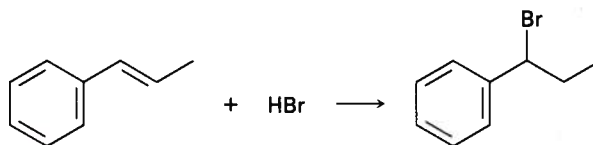


GENERAL PROBLEMS

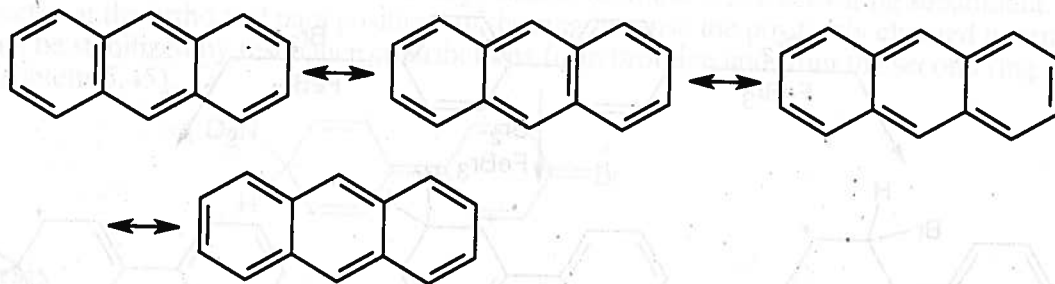
- 5.50 We said in Section 4.9 that an allylic carbocation is stabilized by resonance. Draw resonance structures to account for the similar stabilization of a benzylic carbocation.



- 5.51 Addition of HBr to 1-phenylpropene yields (1-bromopropyl)benzene as the only product. Propose a mechanism for the reaction, and explain why none of the other regioisomer is produced (see Problem 5.50).

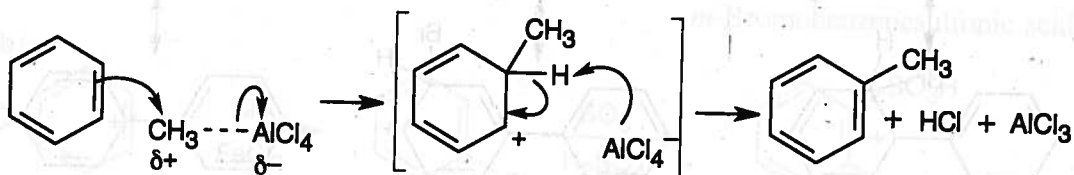
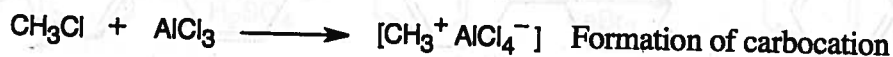


5.42



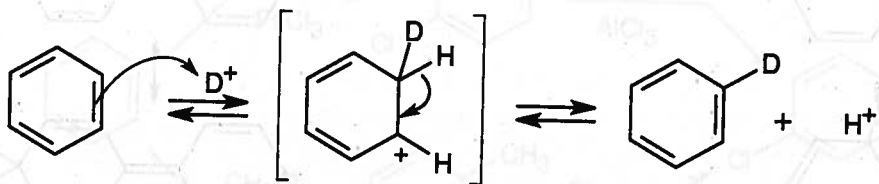
Mechanisms

5.43

Attack of ring π electrons
on carbocation

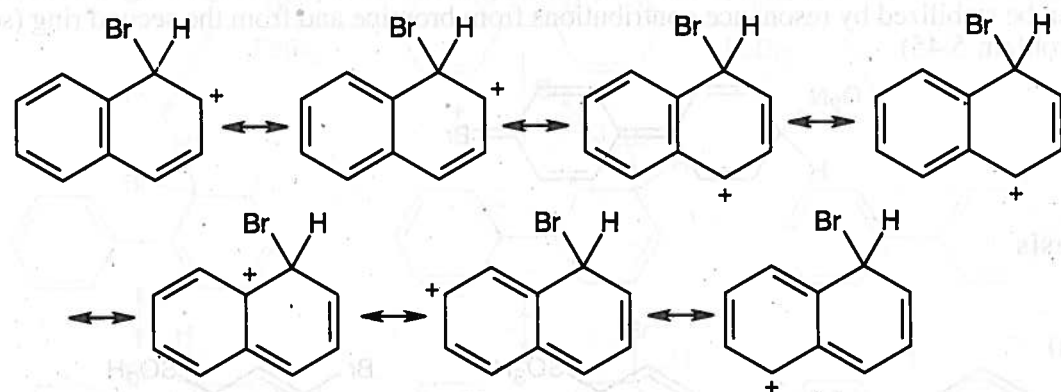
Loss of proton

5.44

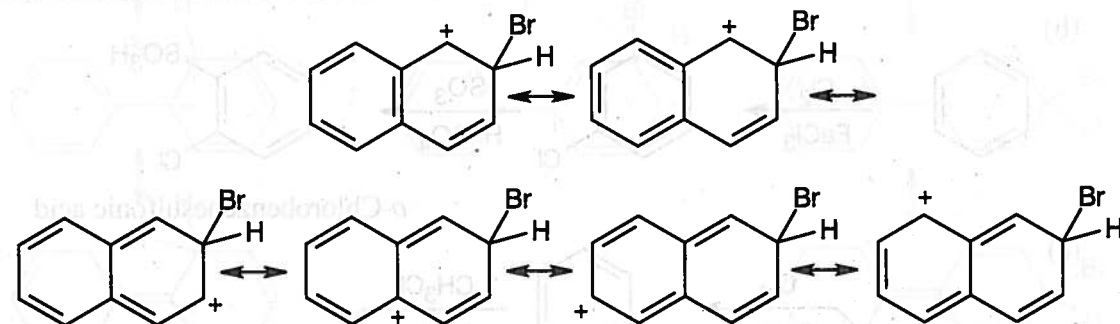


Benzene can be protonated by strong acids. The resulting intermediate can lose either deuterium or hydrogen. If H^+ is lost, deuterated benzene is produced. Attack on D^+ can occur at all positions of the ring and leads to eventual replacement of all hydrogens by deuterium. Only the first step is shown.

5.49 Resonance forms for the intermediate from attack at C1:



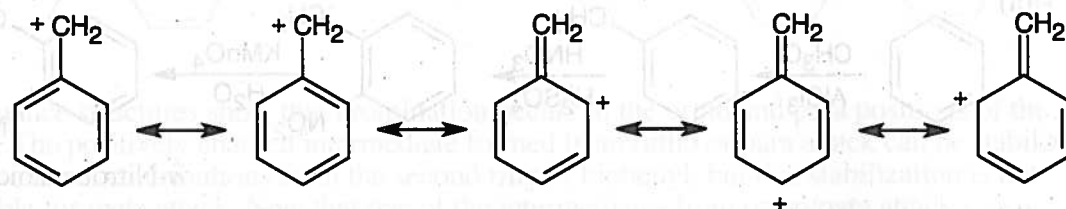
Resonance forms for the intermediate from attack at C2:



There are seven resonance forms for attack at C1 and six for attack at C2. For C1 attack, the second ring is fully aromatic in four of the resonance forms. In the other three forms, the positive charge has been delocalized into the second ring, destroying the ring's aromaticity. For C2 attack, the second ring is fully aromatic in only the first two forms. Since stabilization is lost when aromaticity is disturbed, the intermediate from C2 attack is less stable than the intermediate from C1 attack, and C1 attack is favored.

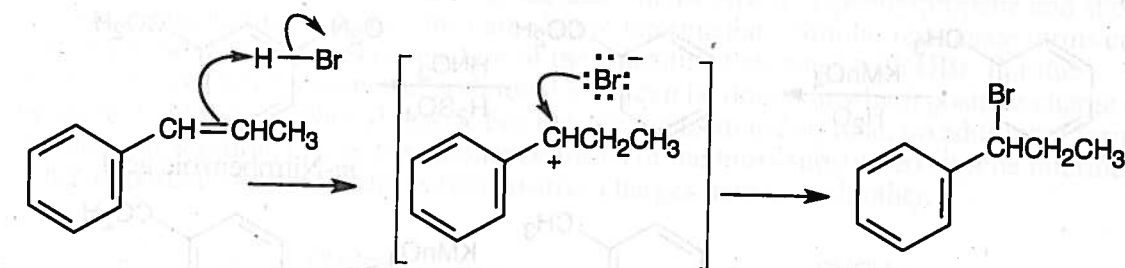
General Problems

5.50



A benzylic carbocation is stabilized because its positive charge can be delocalized over the π system of the aromatic ring.

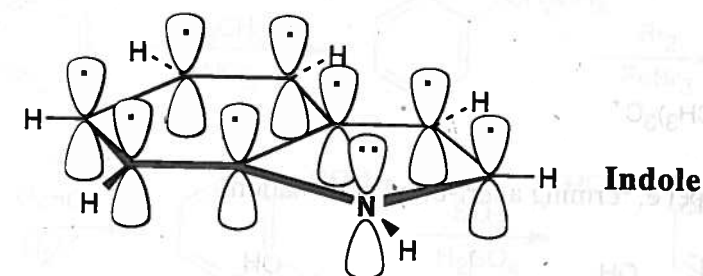
5.51



Protonation of the double bond at carbon 2 of 1-phenylpropene leads to an intermediate that can be stabilized by resonance involving the aromatic ring.

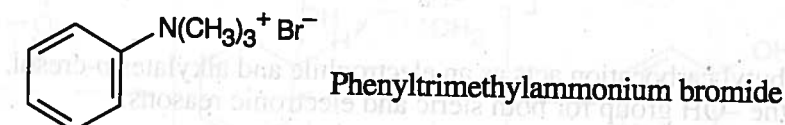
- 5.52 (a) Chlorination of toluene occurs at the ortho and para positions. To synthesize the given product, first oxidize toluene to benzoic acid and then chlorinate.
- (b) A *tert*-butyl group can't be oxidized by KMnO_4 to a $-\text{CO}_2\text{H}$ group because it has no benzylic hydrogens. To obtain the desired compound, alkylate chlorobenzene with CH_3Cl and AlCl_3 and then oxidize.

5.53



Indole, like naphthalene, has ten π electrons in two rings and is aromatic. Two π electrons come from the nitrogen atom, whereas in naphthalene all come from the ring carbons.

5.54



The trimethylammonium group is deactivating because it is positively charged and because it has no lone-pair electrons to donate to the aromatic ring.

Summary and Key Words

achiral 193
 chiral 191
 chiral environment 212
 chirality center 191
 configuration 197
 dextrorotatory 195
 diastereomers 202
 enantiomers 190
 levorotatory 195
 meso compound 205
 optical activity 195
R configuration 198
 racemate (racemic mixture) 206
 resolution 206
S configuration 198
 specific rotation, $[\alpha]_D$ 196

In this chapter, we've looked at some of the causes and consequences of molecular handedness—a topic crucial to understanding organic and biological chemistry. The subject can be a bit complex, but it is so important that it's worthwhile spending the time needed to become familiar with it.

A molecule that is not identical to its mirror image is said to be **chiral**, meaning “handed.” A chiral molecule is one that does not contain a plane of symmetry. The usual cause of chirality is the presence of a tetrahedral carbon atom bonded to four different groups—a so-called **chirality center**. Chiral compounds can exist as a pair of mirror-image stereoisomers called **enantiomers**, which are related to each other as a right hand is related to a left hand. When a beam of plane-polarized light is passed through a solution of a pure enantiomer, the plane of polarization is rotated, and the compound is said to be **optically active**.

The three-dimensional **configuration** of a chirality center is specified as either *R* or *S*. Sequence rules are used to rank the four substituents on the chiral carbon, and the molecule is then oriented so that the lowest-ranked group points directly away from the viewer. If a curved arrow drawn in the direction of decreasing rank for the remaining three groups is clockwise, the chirality center has the *R* configuration. If the direction is counterclockwise, the chirality center has the *S* configuration.

Some molecules have more than one chirality center. Enantiomers have opposite configurations at all chirality centers, whereas **diastereomers** have the same configuration in at least one center but opposite configurations at the others. **Meso compounds** contain chirality centers but are achiral overall because they contain a plane of symmetry. **Racemates** are 50:50 mixtures of (+) and (–) enantiomers. Racemic mixtures and individual diastereomers differ in both their physical properties and their biological properties and can often be **resolved**.

Exercises

Visualizing Chemistry

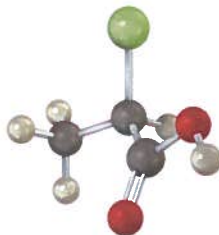
(Problems 6.1–6.20 appear within the chapter.)



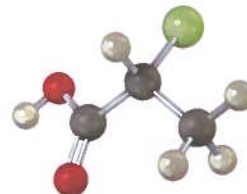
Interactive versions of these problems are assignable in OWL.

6.21 Which of the following structures are identical? (Red = O, yellow-green = Cl.)

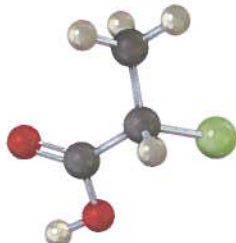
(a)



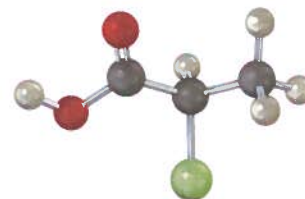
(b)



(c)

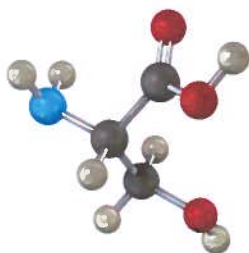


(d)



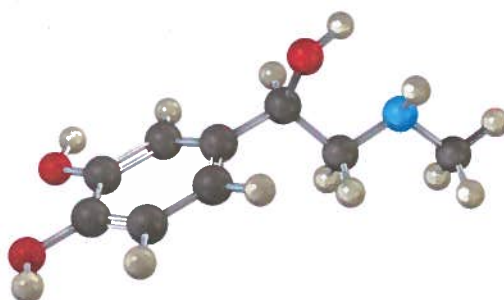
6.22 Assign *R* or *S* configuration to the chirality centers in the following molecules (red = O, blue = N):

(a)



Serine

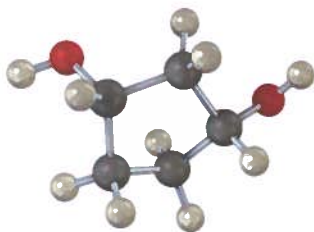
(b)



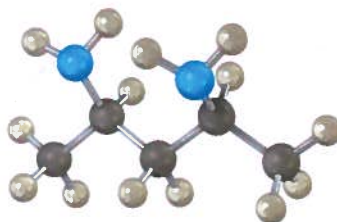
Adrenaline

6.23 Which, if any, of the following structures represent meso compounds? (Red = O, blue = N, yellow-green = Cl.)

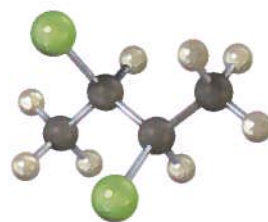
(a)



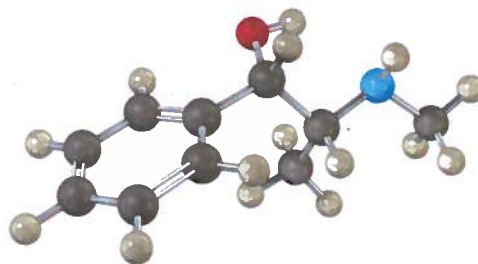
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(c)

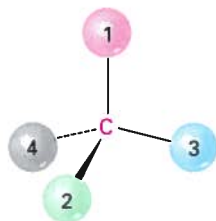


6.24 Assign *R* or *S* configuration to each chirality center in pseudoephedrine, an over-the-counter decongestant found in cold remedies (red = O, blue = N).

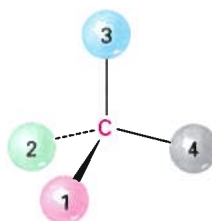


6.25 Orient each of the following drawings so that the lowest-ranked group is toward the rear, and then assign *R* or *S* configuration:

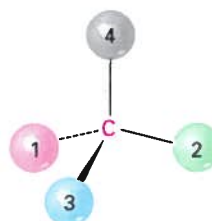
(a)



(b)



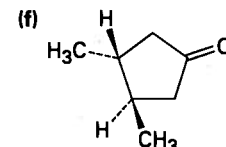
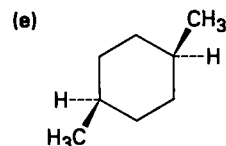
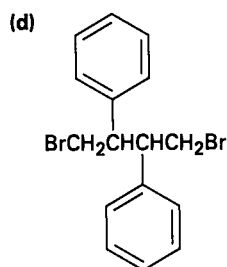
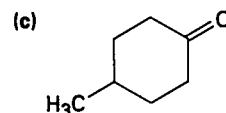
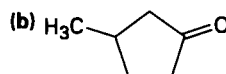
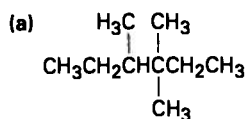
(c)



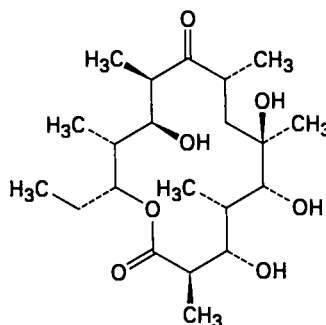
Additional Problems

IDENTIFYING CHIRALITY CENTERS

- 6.26 Which of the following objects are chiral?
 (a) A basketball (b) A fork (c) A wine glass
 (d) A golf club (e) A monkey wrench (f) A snowflake
- 6.27 Which of the following compounds are chiral?
 (a) 2,4-Dimethylheptane (b) 5-Ethyl-3,3-dimethylheptane
 (c) *cis*-1,3-Dimethylcyclohexane (d) 4,5-Dimethylocta-2,6-diene
- 6.28 Draw chiral molecules that meet the following descriptions:
 (a) A chloroalkane, $C_5H_{11}Cl$ (b) An alcohol, $C_6H_{14}O$
 (c) An alkene, C_6H_{12} (d) An alkane, C_8H_{18}
- 6.29 Which of the following compounds are chiral? Label all chirality centers.



- 6.30 There are eight alcohols with the formula $C_5H_{12}O$. Draw them, and tell which are chiral.
- 6.31 Propose structures for compounds that meet the following descriptions:
 (a) A chiral alcohol with four carbons
 (b) A chiral carboxylic acid
 (c) A compound with two chirality centers
- 6.32 Erythronolide B, the biological precursor of the broad-spectrum antibiotic erythromycin, has ten chirality centers. Identify them with asterisks.



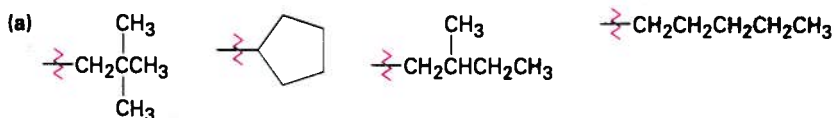
Erythronolide B

OPTICAL ACTIVITY

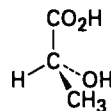
- 6.33 Cholic acid, the major steroid found in bile, was found to have a rotation of $+2.22^\circ$ when a 3.00 g sample was dissolved in 5.00 mL of alcohol in a sample tube with a 1.00 cm pathlength. Calculate $[\alpha]_D$ for cholic acid.
- 6.34 Polarimeters are so sensitive that they can measure rotations to the thousandth of a degree, an important advantage when only small amounts of a sample are available. For example, when 7.00 mg of ecdysone, an insect hormone that controls molting in the silkworm moth, was dissolved in 1.00 mL of chloroform in a cell with a 2.00 cm pathlength, an observed rotation of $+0.087^\circ$ was found. Calculate $[\alpha]_D$ for ecdysone.
- 6.35 Naturally occurring (*S*)-serine has $[\alpha]_D = -6.83$. What specific rotation do you expect for (*R*)-serine?

 ASSIGNING *R,S*
 CONFIGURATION
 TO CHIRALITY CENTERS

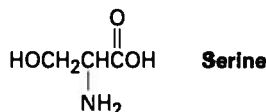
- 6.36 Rank the substituents in each of the following sets:
- (a) $-\text{H}$, $-\text{OH}$, $-\text{OCH}_3$, $-\text{CH}_3$
 (b) $-\text{Br}$, $-\text{CH}_3$, $-\text{CH}_2\text{Br}$, $-\text{Cl}$
 (c) $-\text{CH}=\text{CH}_2$, $-\text{CH}(\text{CH}_3)_2$, $-\text{C}(\text{CH}_3)_3$, $-\text{CH}_2\text{CH}_3$
 (d) $-\text{CO}_2\text{CH}_3$, $-\text{COCH}_3$, $-\text{CH}_2\text{OCH}_3$, $-\text{OCH}_3$
- 6.37 Rank the substituents in each of the following sets:



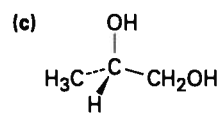
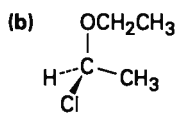
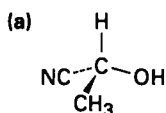
- 6.38 One enantiomer of lactic acid is shown below. Is it *R* or *S*? Draw its mirror image in the standard tetrahedral representation.



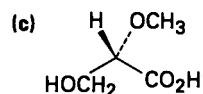
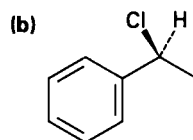
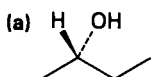
- 6.39 Draw tetrahedral representations of both enantiomers of the amino acid serine. Tell which of your structures is *S* and which is *R*.



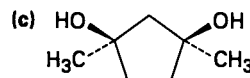
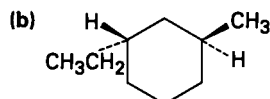
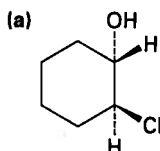
- 6.40 Assign *R* or *S* configuration to the chirality centers in the following molecules:



6.41 Assign *R* or *S* configuration to the chirality centers in the following molecules:



6.42 Assign *R* or *S* configuration to each chirality center in the following biological molecules:



STEREOCHEMICAL RELATIONSHIPS

6.43 What is the relationship between the specific rotations of (2*R*,3*R*)-pentane-2,3-diol and (2*S*,3*S*)-pentane-2,3-diol? Between (2*R*,3*S*)-pentane-2,3-diol and (2*R*,3*R*)-pentane-2,3-diol?

6.44 What is the stereochemical configuration of the enantiomer of (2*S*,4*R*)-dibromooctane?

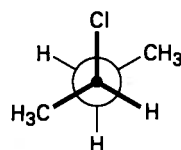
6.45 What are the stereochemical configurations of the two diastereomers of (2*S*,4*R*)-dibromooctane?

6.46 Draw examples of the following:

(a) A meso compound with the formula C_8H_{18}

(b) A compound with two chirality centers, one *R* and the other *S*

6.47 Tell whether the following Newman projection of 2-chlorobutane is *R* or *S* (You might want to review Section 2.5.)



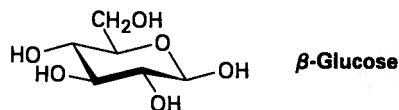
6.48 Draw a Newman projection that is enantiomeric with the one shown in Problem 6.47.

6.49 Draw a Newman projection of *meso*-tartaric acid.

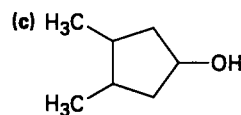
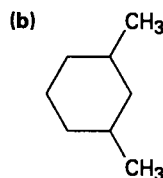
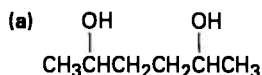
6.50 Draw Newman projections of (2*R*,3*R*)- and (2*S*,3*S*)-tartaric acid, and compare them to the projection you drew in Problem 6.49 for the *meso* form.

GENERAL PROBLEMS

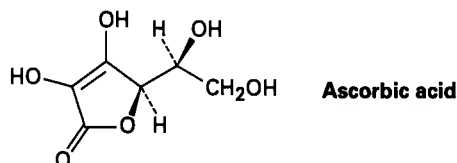
6.51 β -Glucose has the following structure. Identify the chirality centers in β -glucose, and tell how many stereoisomers of glucose are possible.



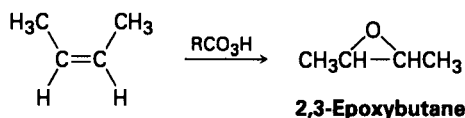
- 6.52 Draw a tetrahedral representation of (*R*)-3-chloropent-1-ene.
- 6.53 Draw the two *cis*-*trans* stereoisomers of 1,2-dimethylcyclopentane, assign *R,S* configurations to the chirality centers, and indicate whether the stereoisomers are chiral or meso.
- 6.54 Draw the meso form of each of the following molecules, and indicate the plane of symmetry in each:



- 6.55 Assign *R* or *S* configuration to the chirality centers in ascorbic acid (vitamin C).

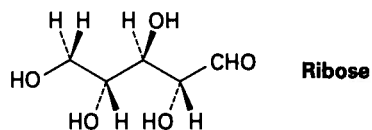


- 6.56 We saw in Section 4.6 that alkenes undergo reaction with peroxycarboxylic acids to give epoxides. For example, *cis*-but-2-ene gives 2,3-epoxybutane:



Assuming that both C–O bonds form from the same side of the double bond (*syn* stereochemistry; Section 4.5), show the stereochemistry of the product. Is the epoxide chiral? Is it optically active?

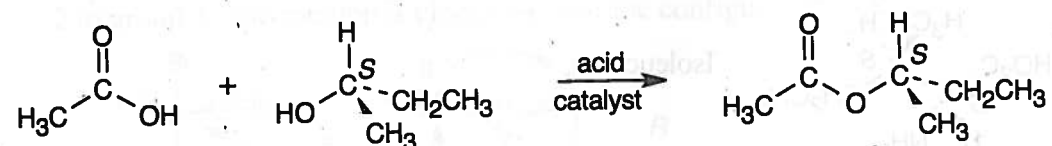
- 6.57 Ribose, an essential part of ribonucleic acid (RNA), has the following structure:



How many chirality centers does ribose have? Identify them with asterisks. How many stereoisomers of ribose are there?

- 6.58 Draw the structure of the enantiomer of ribose (Problem 6.57).
- 6.59 Draw the structure of a diastereomer of ribose (Problem 6.57).

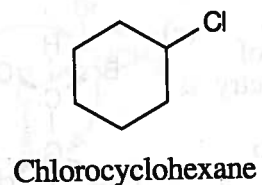
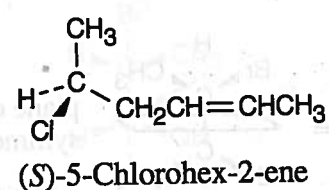
6.19



The product is the pure *S* ester because no bonds at the chiral carbon are broken or rearranged during the reaction.

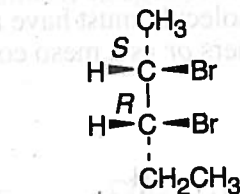
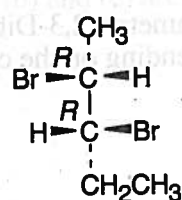
6.20

(a)



These two compounds are constitutional isomers. They are skeletal isomers because they have different carbon skeletons.

(b)

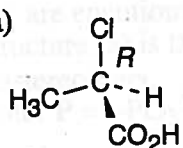


The two dibromopentane stereoisomers are diastereomers.

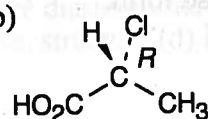
Visualizing Chemistry

6.21

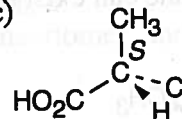
(a)



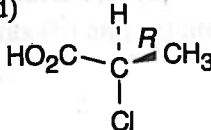
(b)



(c)



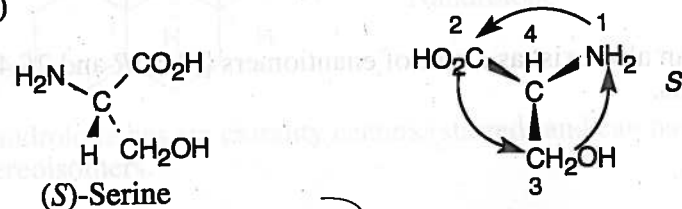
(d)



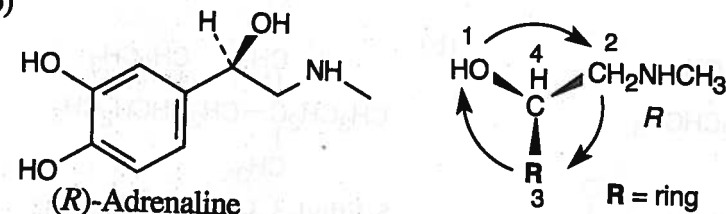
Structures (a), (b), and (d) are identical (*R* enantiomer); structure (c) is the *S* enantiomer.

6.22

(a)

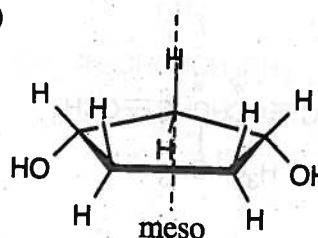


(b)

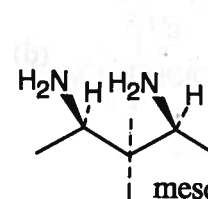


6.23

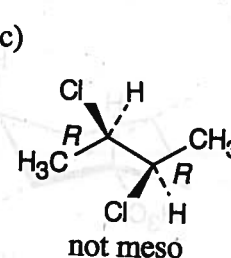
(a)



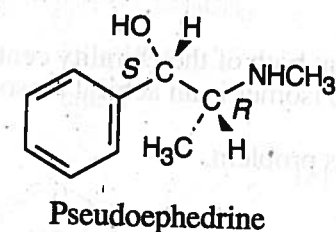
(b)



(c)

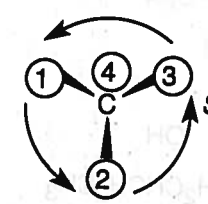
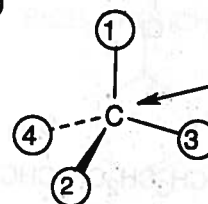


6.24

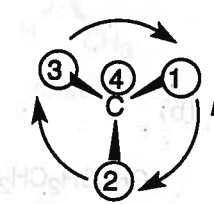
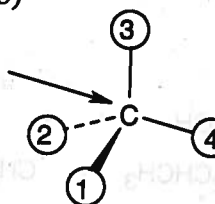


6.25

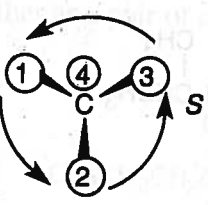
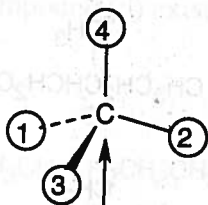
(a)



(b)



(c)

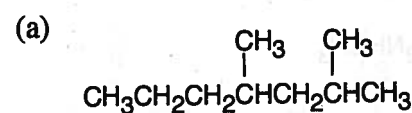
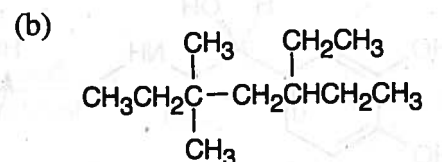
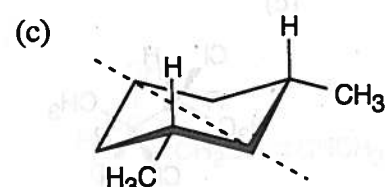
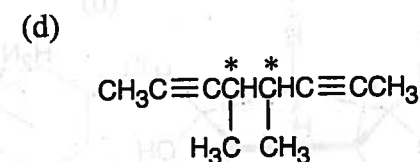


Additional Problems

Identifying Chiral Molecules and Chiral Centers

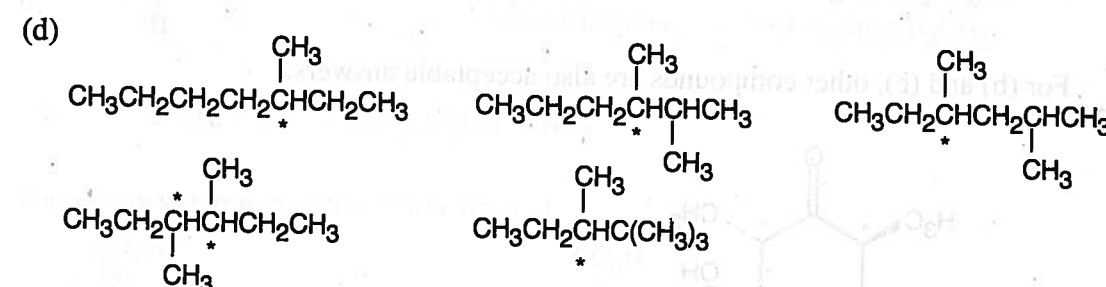
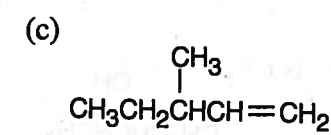
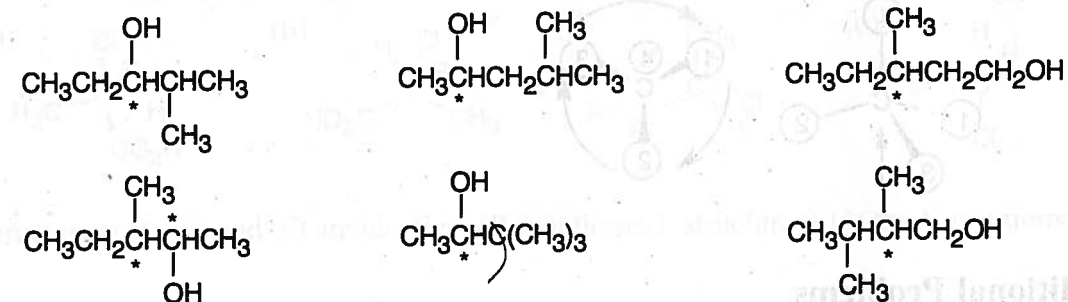
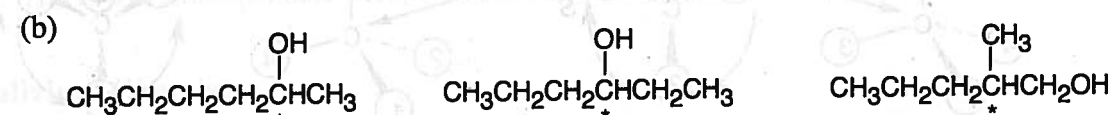
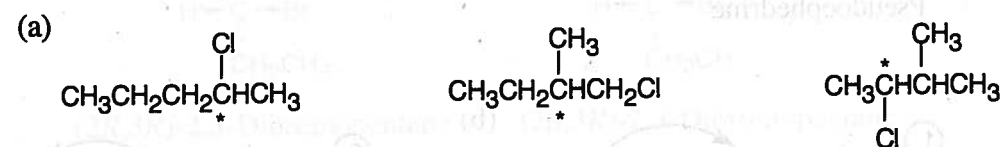
- 6.26 Chiral: (d) golf club, (e) monkey wrench (because of the threads).
 Achiral: (a) basketball, (b) fork, (c) wine glass, (f) snowflake.

6.27

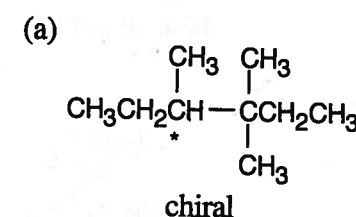
2,4-Dimethylheptane
chiral5-Ethyl-3,3-dimethylheptane
achiral*cis*-1,3-Dimethylcyclohexane
achiral4,5-Dimethyl-2,6-octadiyne
chiral

The chirality of (d) depends on the configurations at both of the chirality centers. The (*R,R*) and (*S,S*) isomers are chiral enantiomers; the (*R,S*) isomer is an achiral meso compound.

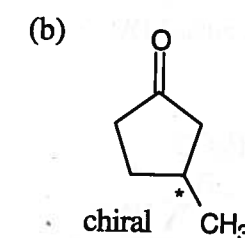
6.28 There are several possibilities for most parts of this problem.



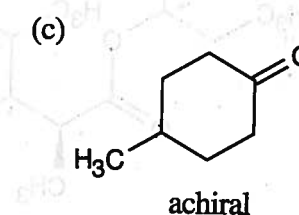
6.29



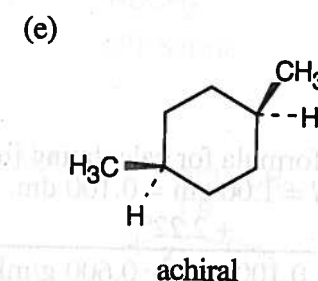
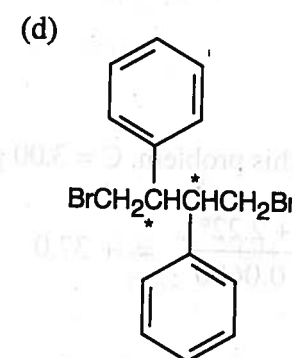
chiral



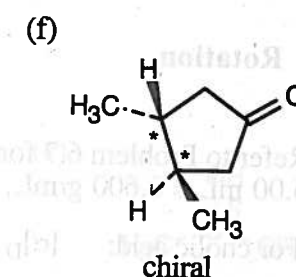
chiral



achiral



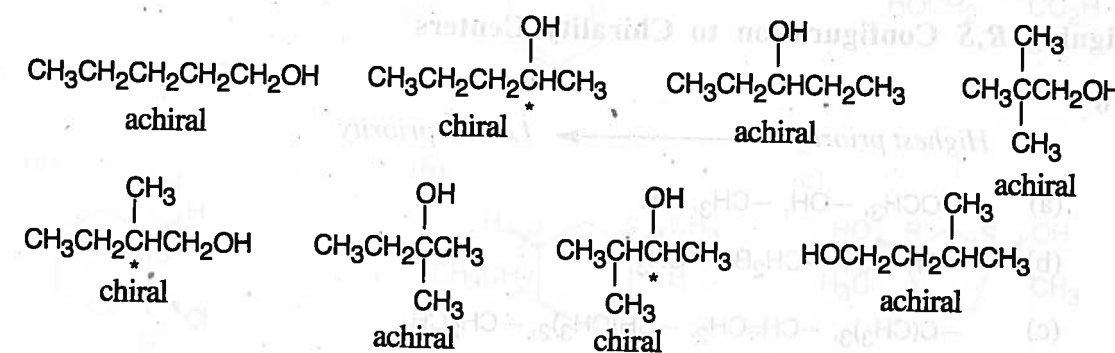
achiral



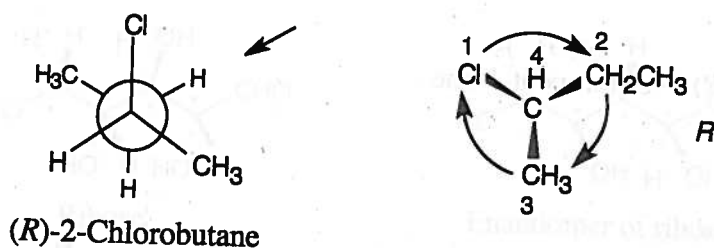
chiral

Compound (d) exists either as a pair of chiral enantiomers or as an achiral meso compound.

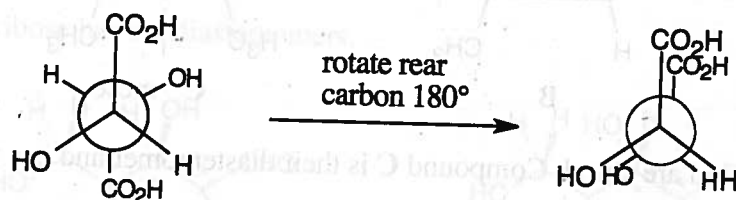
6.30



6.48

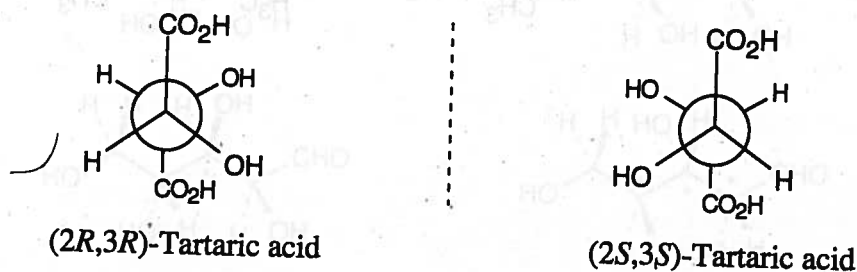


6.49



The mirror plane of *meso*-tartaric acid is more apparent if the molecule is shown in its eclipsed conformation.

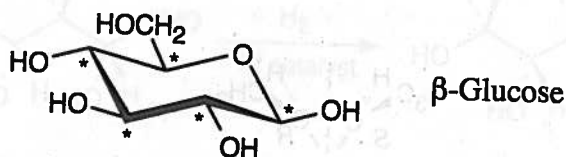
6.50



The enantiomeric tartaric acids are mirror images of each other. Unlike the *meso* isomer, neither of the above enantiomers contains a mirror plane.

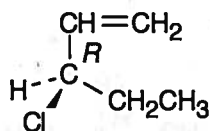
General Problems

6.51



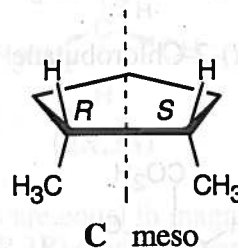
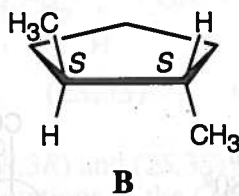
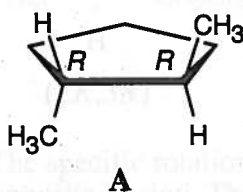
The number of stereoisomers of a chiral compound is given by 2^n , where n equals the number of chirality centers present. Here, $n = 5$ and $2^n = 32$. Glucose thus has 32 possible stereoisomers.

6.52



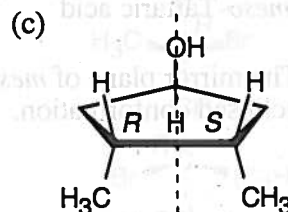
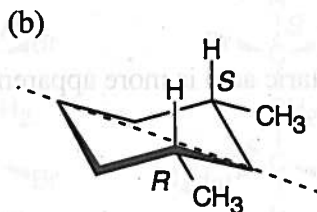
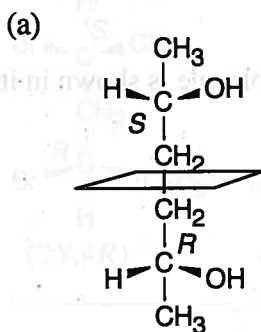
(R)-3-Chloropent-1-ene

6.53

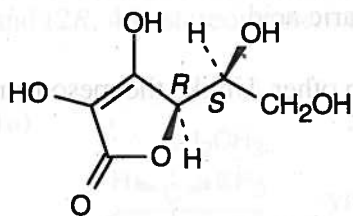


A and **B** are enantiomers and are chiral. Compound **C** is their diastereomer and is a meso compound.

6.54

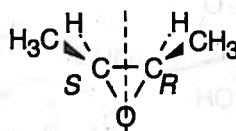
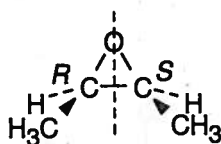


6.55



Ascorbic acid

6.56



Peroxydicarboxylic acids can attack either the "top" side or the "bottom" side of a double bond. The epoxide resulting from top side attack, pictured above, has two chirality centers, but because it has a plane of symmetry it is a meso compound. The epoxide resulting from bottom side attack is identical to epoxide resulting from top-side attack.

Summary and Key Words

alkyl halide 223
bimolecular reaction 231
carbanion 227
E1 reaction 240
E1cB reaction 241
E2 reaction 239
Grignard reagent 226
nucleophilic substitution
reaction 228
organohalide 222
S_N1 reaction 234
S_N2 reaction 230
unimolecular reaction 234
Zaitsev's rule 237

Alkyl halides are not often found in terrestrial organisms, but the reactions they undergo are among the most important and well-studied reaction types in organic chemistry. In this chapter, we saw how to name and prepare alkyl halides, and we made a detailed study of their substitution and elimination reactions.

Alkyl halides are usually prepared from alcohols by treatment either with HX (for tertiary alcohols) or with SOCl₂ or PBr₃ (for primary and secondary alcohols). Alkyl halides react with magnesium metal to form organomagnesium halides, called **Grignard reagents (RMgX)**. Because Grignard reagents are nucleophilic and basic, they react with acids to yield hydrocarbons.

Treatment of an alkyl halide with a nucleophile/base results either in substitution or elimination. **Nucleophilic substitution reactions** occur by two mechanisms: S_N2 and S_N1. In the **S_N2 reaction**, the entering nucleophile attacks the substrate from a direction 180° away from the leaving group, resulting in an umbrella-like inversion of configuration at the carbon atom. S_N2 reactions are strongly inhibited by increasing steric bulk of the reagent and are favored only for primary substrates and simple secondary substrates. In the **S_N1 reaction**, the substrate spontaneously dissociates to a carbocation, which reacts with a nucleophile in a second step. As a consequence, S_N1 reactions take place with racemization of configuration at the carbon atom and are favored only for tertiary substrates.

Elimination reactions occur commonly by three mechanisms—E2, E1, and E1cB—which differ in the timing of C–X and C–H bond-breaking. In the **E2 reaction**, a base abstracts a hydrogen at the same time that the adjacent halide group departs. The E2 reaction usually gives a mixture of alkene products in which the more highly substituted alkene predominates (**Zaitsev's rule**). In the **E1 reaction**, C–X bond-breaking occurs first. The substrate spontaneously dissociates to form a carbocation, which subsequently loses H⁺ from a neighboring carbon. In the **E1cB reaction**, C–H bond-breaking occurs first. A base removes H⁺ to give a **carbanion** intermediate, followed by loss of the leaving halide group from the adjacent carbon. Biological elimination reactions typically occur by this E1cB mechanism.

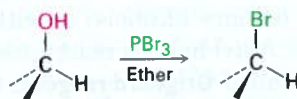
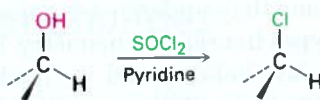
Summary of Reactions

1. Synthesis of alkyl halides from alcohols (Section 7.2)
 - (a) Reaction of alcohols with HX, where X = Cl, Br



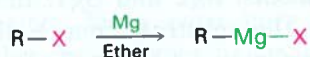
Reactivity order: 3° > 2° > 1°

(b) Reaction of primary and secondary alcohols with SOCl_2 and PBr_3



2. Reactions of alkyl halides

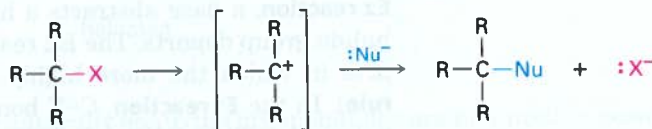
(a) Formation of Grignard reagents (Section 7.3)



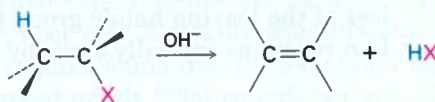
(b) $\text{S}_{\text{N}}2$ reaction: backside attack of nucleophile on alkyl halide (Section 7.5)



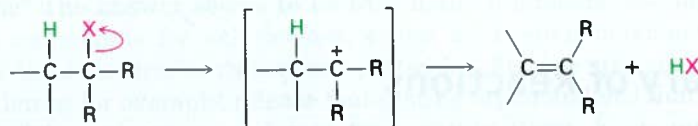
(c) $\text{S}_{\text{N}}1$ reaction: carbocation intermediate is involved (Section 7.6)



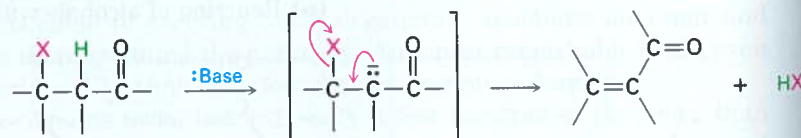
(d) $\text{E}2$ reaction (Section 7.7)



(e) $\text{E}1$ reaction (Section 7.8)



(f) $\text{E}1\text{cB}$ reaction (Section 7.8)



Exercises

Visualizing Chemistry

(Problems 7.1–7.19 appear within the chapter.)



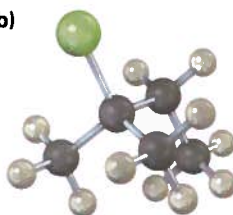
Interactive versions of these problems are assignable in OWL.

- 7.20 Write the product you would expect from reaction of each of the following alkyl halides with (i) $\text{Na}^+ \text{SCH}_3^-$ and (ii) NaOH (yellow-green = Cl):

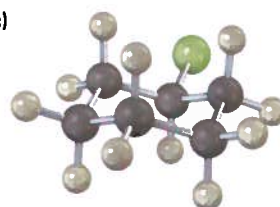
(a)



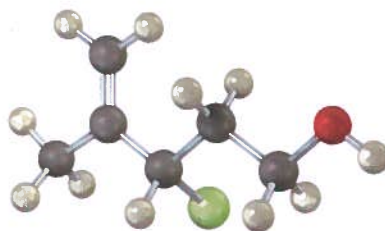
(b)



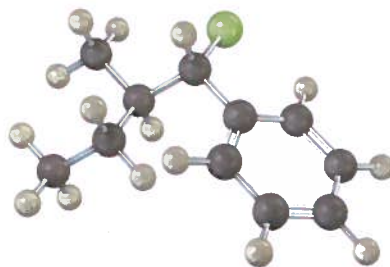
(c)



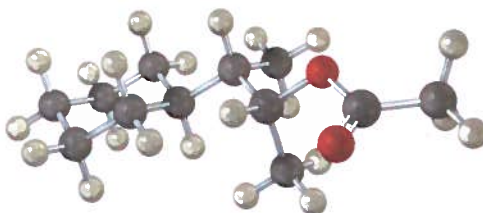
- 7.21 Assign *R* or *S* configuration to the following molecule, write the product you would expect from $\text{S}_\text{N}2$ reaction with NaCN , and assign *R* or *S* configuration to the product (red = O, yellow-green = Cl):



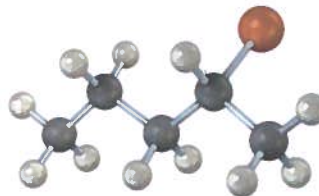
- 7.22 Draw the structure of the product you expect from E2 reaction of the following molecule with NaOH (yellow-green = Cl):



- 7.23 From what alkyl bromide was the following alkyl acetate made by $\text{S}_\text{N}2$ reaction? Write the reaction, showing all stereochemistry.



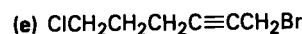
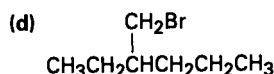
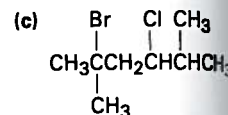
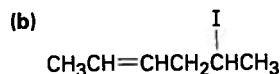
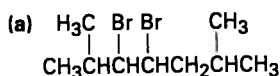
- 7.24 The following alkyl bromide can be prepared by reaction of the alcohol (*S*)-pentan-2-ol with PBr_3 . Name the compound, assign (*R*) or (*S*) stereochemistry, and tell whether the reaction of the alcohol with PBr_3 occurs with retention of the same stereochemistry or with a change in stereochemistry (reddish brown = Br).



Additional Problems

NAMING ALKYL HALIDES

- 7.25 Name the following alkyl halides:



- 7.26 Draw structures corresponding to the following IUPAC names:

(a) 2,3-Dichloro-4-methylhexane

(b) 4-Bromo-4-ethyl-2-methylhexane

(c) 3-Iodo-2,2,4,4-tetramethylpentane

- 7.27 Draw and name the monochlorination products you might obtain by reaction of 2-methylpentane with Cl_2 . Which of the products are chiral?

CHARACTERISTICS OF $\text{S}_{\text{N}}1$ AND $\text{S}_{\text{N}}2$ REACTIONS

- 7.28 Describe the effects of the following variables on both $\text{S}_{\text{N}}2$ and $\text{S}_{\text{N}}1$ reactions:

(a) Substrate structure (b) Leaving group

- 7.29 Which ion in each of the following pairs is a better leaving group?

(a) F^- or Br^- (b) Cl^- or NH_2^- (c) OH^- or I^-

- 7.30 Which alkyl halide in each of the following pairs will react faster in an $\text{S}_{\text{N}}2$ reaction with OH^- ?

(a) Bromobenzene or benzyl bromide, $\text{C}_6\text{H}_5\text{CH}_2\text{Br}$

(b) CH_3Cl or $(\text{CH}_3)_3\text{CCl}$

(c) $\text{CH}_3\text{CH}=\text{CHBr}$ or $\text{H}_2\text{C}=\text{CHCH}_2\text{Br}$

- 7.31 What effect would you expect the following changes to have on the $\text{S}_{\text{N}}2$ reaction of CH_3Br and CN^- to give CH_3CN ?

(a) The concentration of CH_3Br is tripled and that of CN^- is halved.

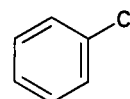
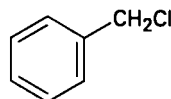
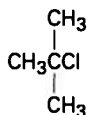
(b) The concentration of CH_3Br is halved and that of CN^- is tripled.

(c) The concentration of CH_3Br is tripled and that of CN^- is doubled.

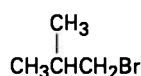
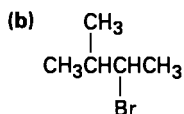
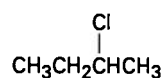
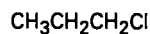
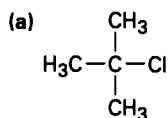
(d) The reaction temperature is raised.

(e) The volume of the reacting solution is doubled by addition of more solvent.

- 7.32 What effect would you expect the following changes to have on the S_N1 reaction of $(CH_3)_3CBr$ with CH_3OH to give $(CH_3)_3COCH_3$?
- The concentration of $(CH_3)_3CBr$ is doubled and that of CH_3OH is halved.
 - The concentration of $(CH_3)_3CBr$ is halved and that of CH_3OH is doubled.
 - The concentrations of both $(CH_3)_3CBr$ and CH_3OH are tripled.
 - The reaction temperature is lowered.
- 7.33 Order the following compounds with respect to both S_N1 and S_N2 reactivity:

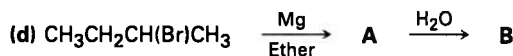
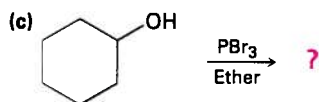
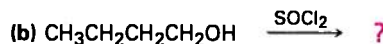
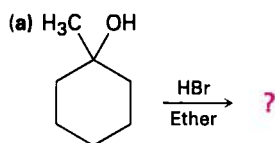


- 7.34 Order each set of compounds with respect to S_N2 reactivity:

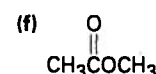
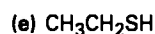
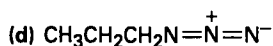
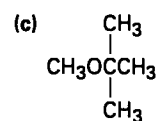
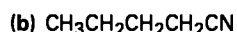
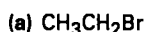


SYNTHESIS

- 7.35 How would you prepare the following compounds, starting with cyclopentene and any other reagents needed?
- Chlorocyclopentane
 - Cyclopentanol
 - Cyclopentylmagnesium chloride
 - Cyclopentane
- 7.36 Predict the product(s) of the following reactions:



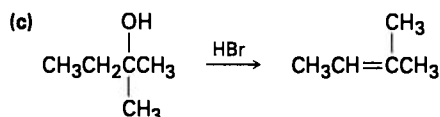
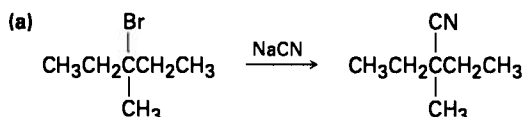
7.37 How might you prepare the following molecules using a nucleophilic substitution reaction at some step?



7.38 What products do you expect from reaction of 1-bromopropane with the following reagents?



7.39 None of the following reactions take place as written. What is wrong with each?

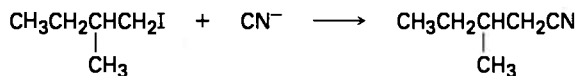


SUBSTITUTIONS AND ELIMINATIONS

7.40 Propose a structure for an alkyl halide that can give a mixture of three alkenes on E2 reaction.

7.41 Heating either *tert*-butyl chloride or *tert*-butyl bromide with ethanol yields the same reaction mixture: approximately 80% *tert*-butyl ethyl ether [$(\text{CH}_3)_3\text{COCH}_2\text{CH}_3$] and 20% 2-methylpropene. Explain why the identity of the leaving group has no effect on the product mixture.

7.42 What effect would you expect the following changes to have on the rate of the reaction of 1-iodo-2-methylbutane with CN^- ?

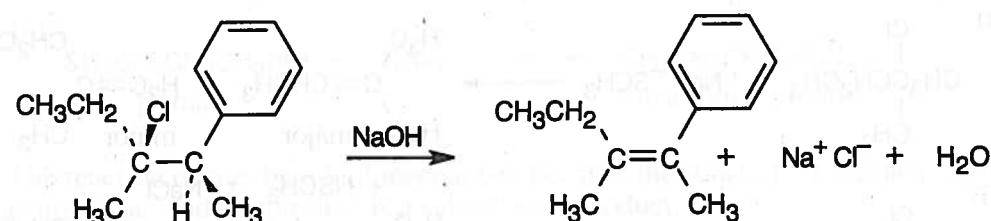


1-Iodo-2-methylbutane

(a) CN^- concentration is halved and 1-iodo-2-methylbutane concentration is doubled.

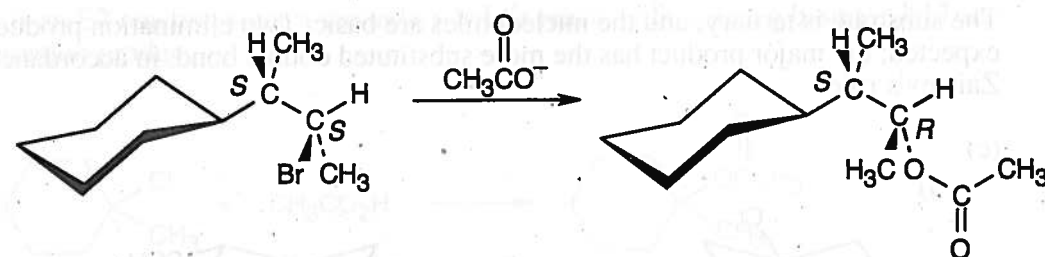
(b) Both CN^- and 1-iodo-2-methylbutane concentrations are tripled.

7.22



According to Zaitsev's rule, the product with the most substituted double bond is most likely to form. Notice also that the double bond that results from elimination is conjugated with the aromatic ring.

7.23



Reaction of the secondary bromide with the weakly basic acetate nucleophile occurs by an S_N2 route, with inversion of configuration, to produce the *R* acetate.

7.24 The name of the compound is (*R*)-2-bromopentane. Reaction of (*S*)-pentan-2-ol with PBr₃ to form (*R*)-2-bromopentane occurs with a change in stereochemistry because the configuration at the chirality center is inverted from *S* to *R*.

Additional Problems

Naming Alkyl Halides

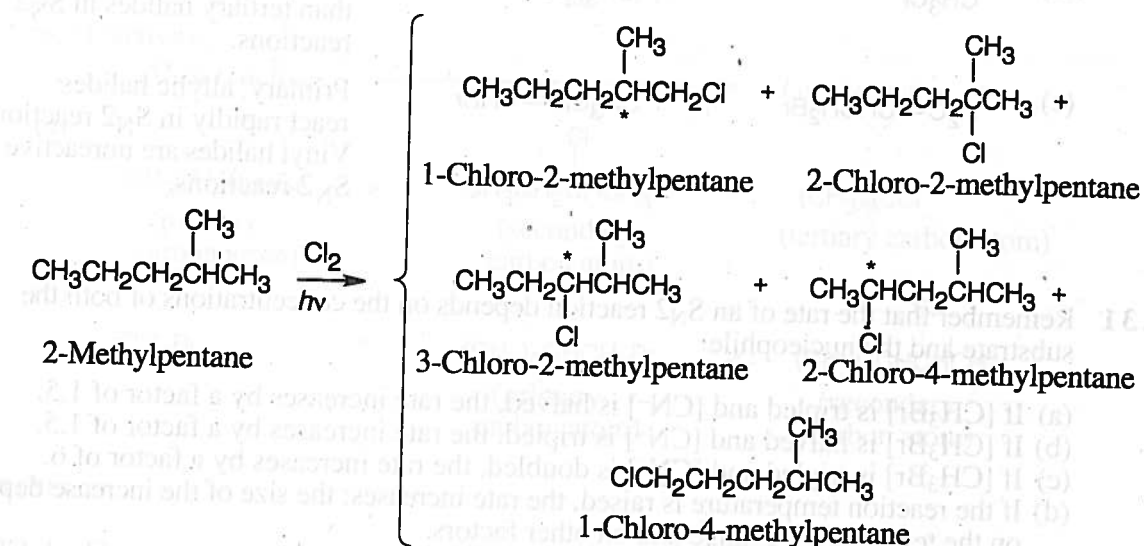
7.25

- (a) CC(Br)C(Br)CC(C)CC
3,4-Dibromo-2,6-dimethylheptane
- (b) CC=CC(I)CC
5-Iodohept-2-ene
- (c) CC(Br)C(C)C(Cl)CC(C)C
2-Bromo-4-chloro-2,5-dimethylhexane
- (d) CCC(CBr)CCC
3-(Bromomethyl)hexane
- (e) ClCCCCC#CCBr
1-Bromo-6-chlorohex-2-yne

7.26

- (a) CC(C)C(Cl)C(Cl)CC
2,3-Dichloro-4-methylhexane
- (b) CC(C)C(Br)CC(C)CC
4-Bromo-4-ethyl-2-methylhexane
- (c) CC(C)C(I)C(C)C(C)C
3-Iodo-2,2,4,4-tetramethylpentane

7.27



Three of the above products are chiral (chirality centers are starred). Each product occurs as a racemic mixture of enantiomers.

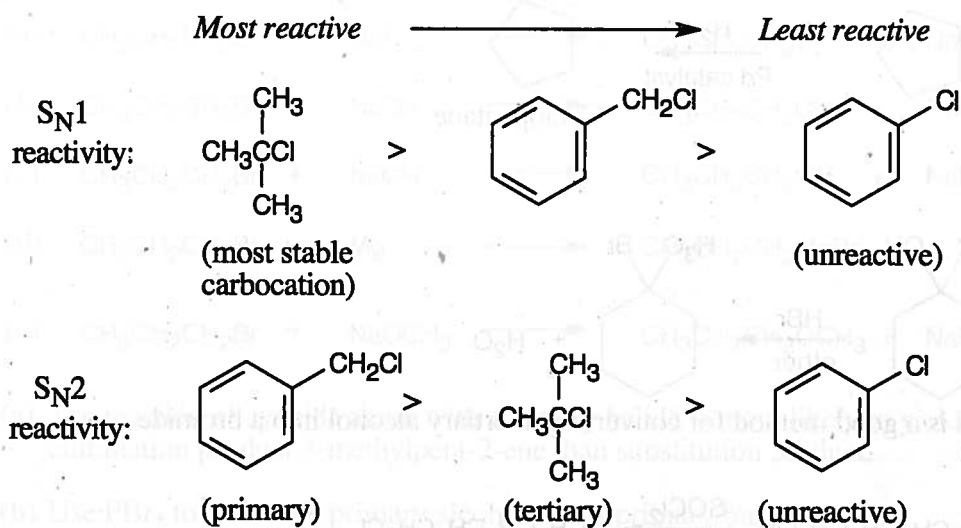
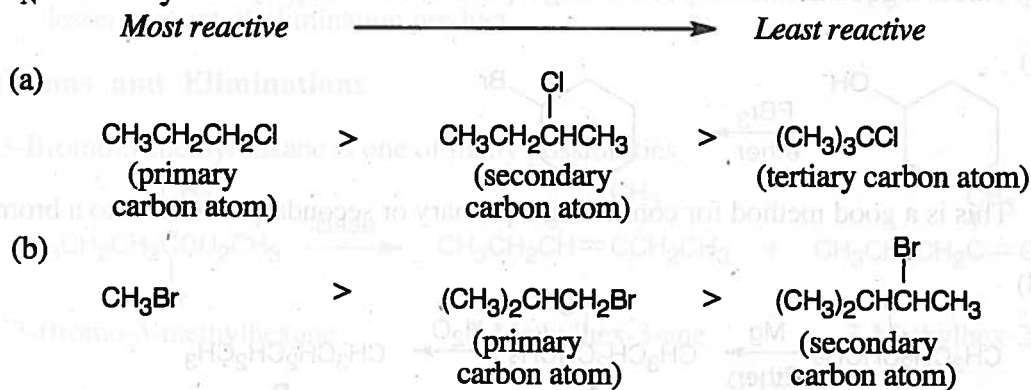
Characteristics of S_N1 and S_N2 Reactions

7.28 (a) S_N2: In an S_N2 reaction, the rate-limiting step involves attack of the nucleophile on the substrate. Consequently, any factor that makes approach of the nucleophile more difficult slows down the rate of reaction. Especially important is the degree of crowding at the reacting carbon atom. Tertiary carbon atoms are too crowded to allow S_N2 substitution to occur. Even steric hindrance one carbon atom away from the reacting site causes a drastic slowdown in the rate of reaction.

S_N1: The rate-limiting step in an S_N1 reaction involves formation of a carbocation. Any structural factor in the substrate that stabilizes carbocations increases the rate of reaction. Substrates that are tertiary, allylic, or benzylic react fastest.

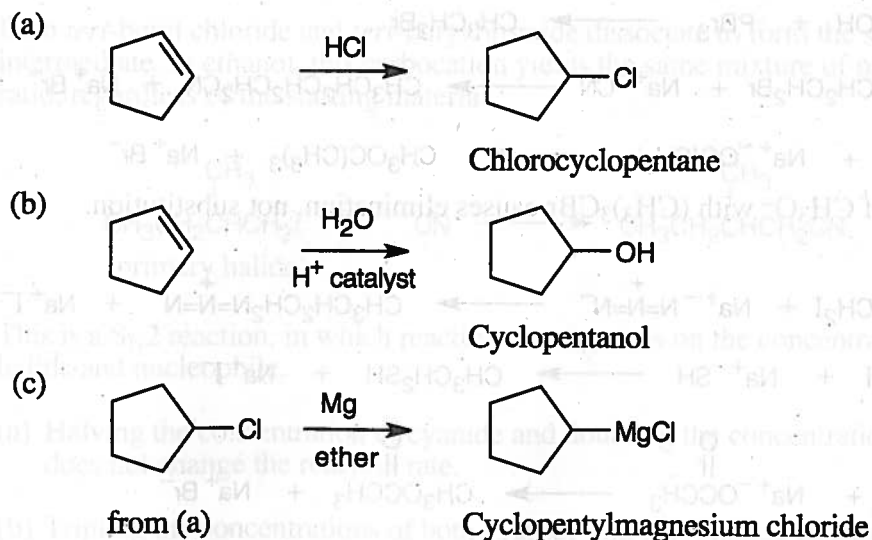
(b) Good leaving groups (stable anions) increase the rates of both S_N1 and S_N2 reactions.

7.33

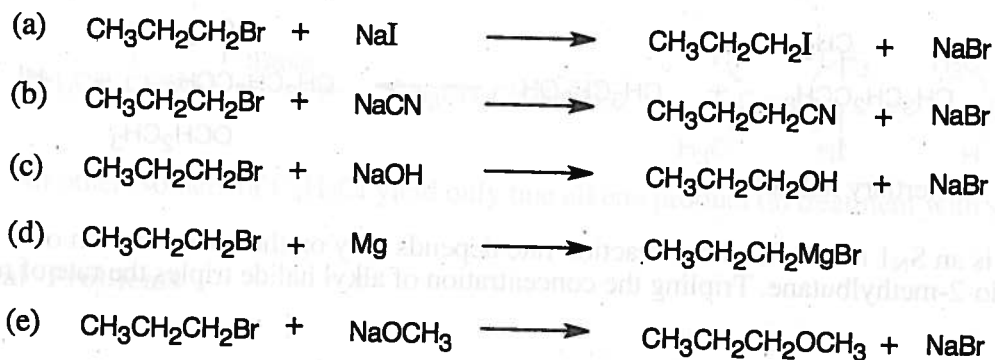
7.34 S_N2 reactivity:

Synthesis

7.35



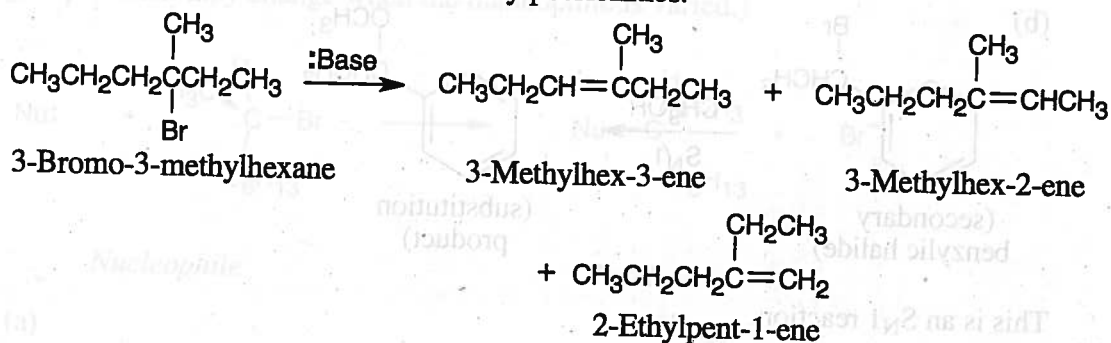
7.38



- 7.39 (a) The reaction of cyanide anion with a tertiary halide is more likely to yield the elimination product 3-methylpent-2-ene than substitution product.
- (b) Use PBr_3 to convert a primary alcohol into a primary bromide.
- (c) Reaction of a tertiary alcohol with HBr gives mainly substitution product along with a lesser amount of elimination product.

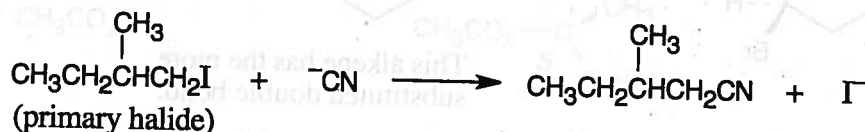
Substitutions and Eliminations

7.40 3-Bromo-3-methylhexane is one of many possibilities.



- 7.41 Both *tert*-butyl chloride and *tert*-butyl bromide dissociate to form the same carbocation intermediate. In ethanol, this carbocation yields the same mixture of products in the same ratio, regardless of the starting material.

7.42



This is a $\text{S}_\text{N}2$ reaction, in which reaction rate depends on the concentration of both alkyl halide and nucleophile.

- (a) Halving the concentration of cyanide and doubling the concentration of alkyl halide does not change the reaction rate.
- (b) Tripling the concentrations of both cyanide and alkyl halide causes a ninefold increase in reaction rate.

Reversible addition of an aldehyde or ketone with water yields a hydrate, also called a **gem diol**. Similarly, aldehydes and ketones react reversibly with alcohols to yield first **hemiacetals** and then **acetals**. Acetals are particularly useful as carbonyl **protecting groups**. Ammonia and primary amines add to aldehydes and ketones to give **imines**, $R_2C=NR'$.

Closely related to the direct 1,2-addition of nucleophiles to aldehydes and ketones is the conjugate **1,4-addition** of nucleophiles to the $C=C$ double bond of α,β -unsaturated aldehydes and ketones. Both direct and conjugate addition reactions are common in biological pathways.

Summary of Reactions

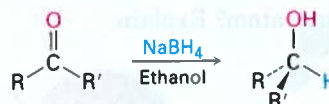
Nucleophilic addition reactions of aldehydes and ketones

1. Reaction with hydride reagents to yield alcohols (Section 9.6)

(a) Reaction of aldehydes to yield primary alcohols

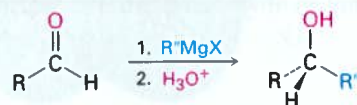


(b) Reaction of ketones to yield secondary alcohols

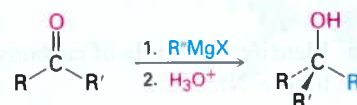


2. Reaction with Grignard reagents to yield alcohols (Section 9.6)

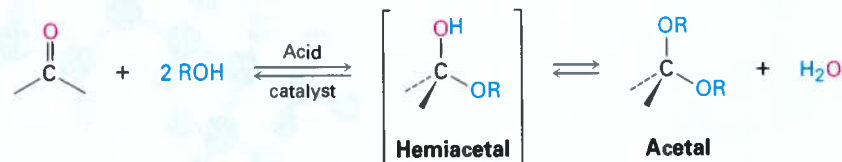
(a) Reaction of aldehydes to yield secondary alcohols



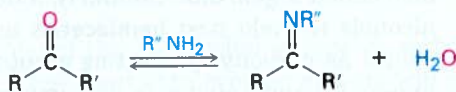
(b) Reaction of ketones to yield tertiary alcohols



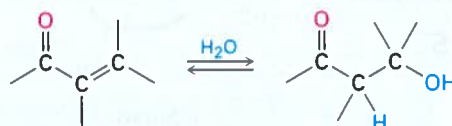
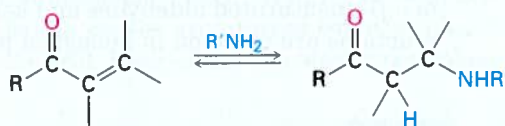
3. Reaction with alcohols to yield acetals (Section 9.8)



4. Reaction with amines to yield imines (Section 9.9)



5. Conjugate (1,4) nucleophilic addition reaction (Section 9.10)



Exercises

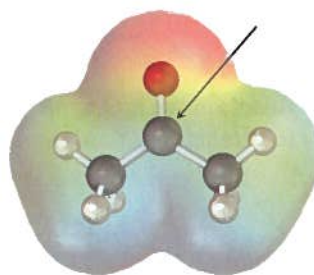
Visualizing Chemistry

(Problems 9.1–9.18 appear within the chapter.)

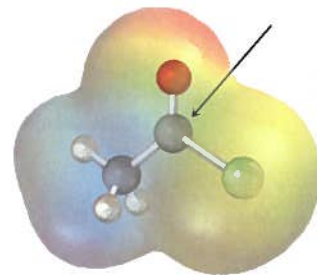


Interactive versions of these problems are assignable in OWL.

- 9.19 Judging from the following electrostatic potential maps, which kind of carbonyl compound has the more electrophilic carbonyl carbon atom, a ketone or an acid chloride? Which has the more nucleophilic carbonyl oxygen atom? Explain.



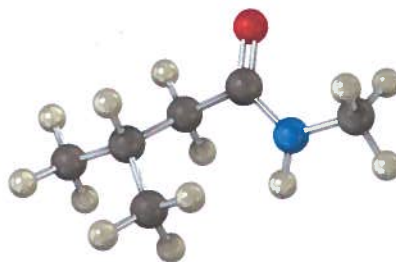
Acetone
(ketone)



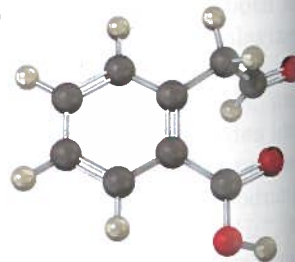
Acetyl chloride
(acid chloride)

- 9.20 Identify the kinds of carbonyl groups in the following molecules (red = O, blue = N):

(a)

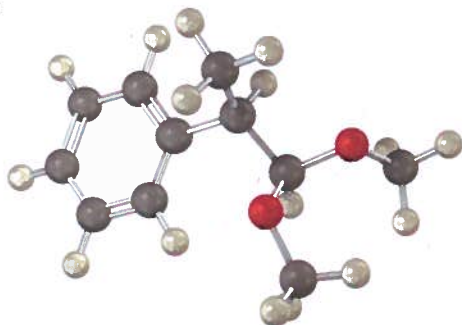


(b)

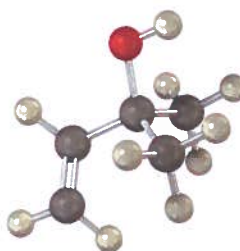


- 9.21** Identify the reactants from which the following molecules were prepared. If an acetal, identify the carbonyl compound and the alcohol; if an imine, identify the carbonyl compound and the amine; if an alcohol, identify the carbonyl compound and the Grignard reagent (red = O, blue = N):

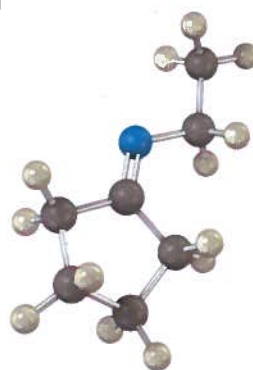
(a)



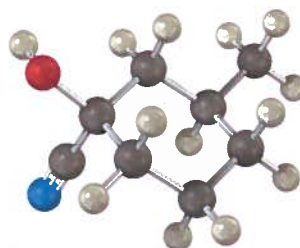
(b)



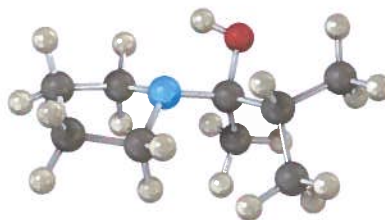
(c)



- 9.22** Compounds called *cyanohydrins* result from the nucleophilic addition of HCN to an aldehyde or ketone. Draw and name the carbonyl compound that the following cyanohydrin was prepared from (red = O, blue = N):



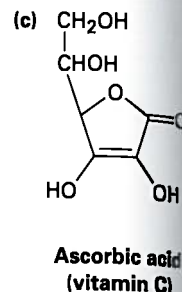
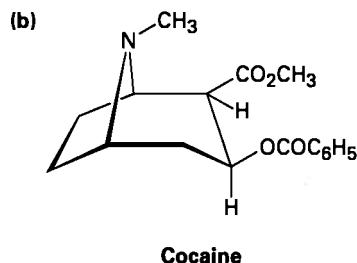
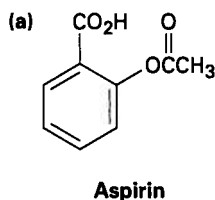
- 9.23** The following model represents the product resulting from addition of a nucleophile to an aldehyde or ketone. Identify the reactants, and write the reaction (red = O, blue = N).



Additional Problems

IDENTIFYING AND
NAMING CARBONYL
COMPOUNDS

9.24 Identify the different kinds of carbonyl functional groups in the following molecules:



9.25 Draw structures corresponding to the following names:

- | | |
|-------------------------------------|-------------------------------|
| (a) Bromoacetone | (b) 3-Methylbutan-2-one |
| (c) 3,5-Dinitrobenzaldehyde | (d) 3,5-Dimethylcyclohexanone |
| (e) 2,2,4,4-Tetramethylpentan-3-one | (f) Butanedial |
| (g) (S)-2-Hydroxypropanal | (h) 3-Phenylprop-2-enal |

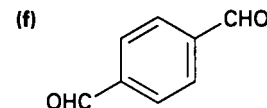
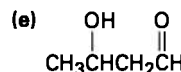
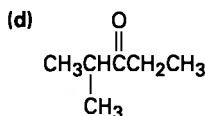
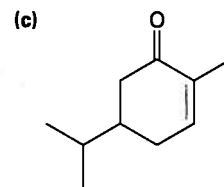
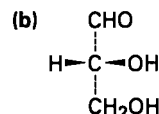
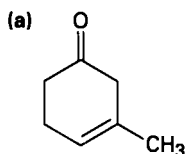
9.26 Draw and name the seven aldehydes and ketones with the formula $C_5H_{10}O$.

9.27 Which of the compounds you identified in Problem 9.26 are chiral?

9.28 Draw structures of molecules that meet the following descriptions:

- | | |
|----------------------------------|-------------------------------------|
| (a) A cyclic ketone, C_6H_8O | (b) A diketone, $C_6H_{10}O_2$ |
| (c) An aryl ketone, $C_9H_{10}O$ | (d) A 2-bromo aldehyde, C_5H_9BrO |

9.29 Give IUPAC names for the following structures:



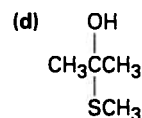
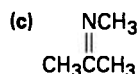
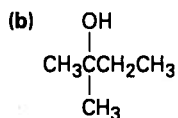
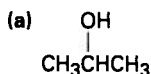
REACTIONS

9.30 Predict the products of the reaction of phenylacetaldehyde, $C_6H_5CH_2CHO$, with the following reagents:

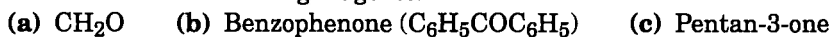
- | | | |
|--------------------------------|-------------------------------|--------------|
| (a) $NaBH_4$, then H_3O^+ | (b) aqueous acidic CrO_3 | (c) NH_2OH |
| (d) CH_3MgBr , then H_3O^+ | (e) CH_3OH , H^+ catalyst | |

9.31 Answer Problem 9.30 for the reaction of acetophenone, $C_6H_5COCH_3$, with the same reagents.

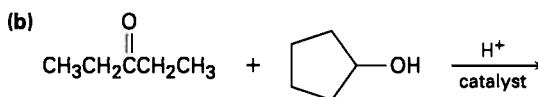
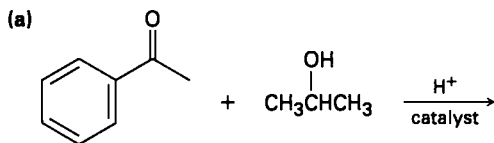
- 9.32 Identify the nucleophile that has added to acetone to give the following products:



- 9.33 Show the products that result from the reaction of phenylmagnesium bromide with the following reagents:



- 9.34 Show the structures of the intermediate hemiacetals and the final acetals that result from the following reactions:

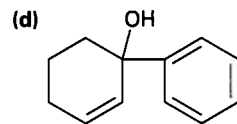
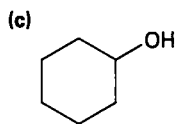
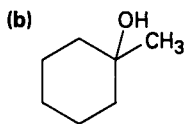
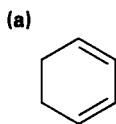


- 9.35 Reaction of butan-2-one with HCN yields a *cyanohydrin* product [$\text{R}_2\text{C}(\text{OH})\text{CN}$] having a new chirality center. Explain why the product is not optically active.

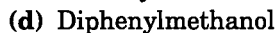
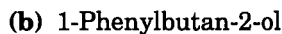
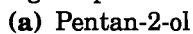
- 9.36 In light of your answer to Problem 9.35, what stereochemistry would you expect the product from the reaction of phenylmagnesium bromide with butan-2-one to have?

SYNTHESIS

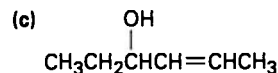
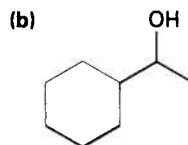
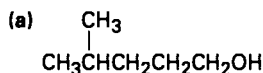
- 9.37 Starting from cyclohex-2-enone and any other reagents needed, how would you prepare the following substances? More than one step may be required.



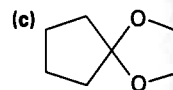
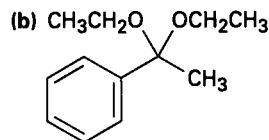
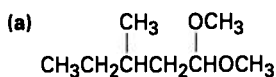
- 9.38 Use a Grignard reaction on an aldehyde or ketone to synthesize the following compounds:



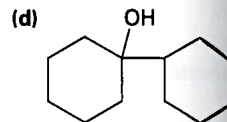
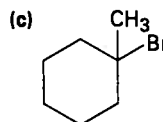
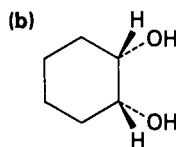
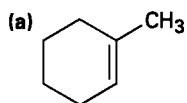
- 9.39 How could you make the following alcohols using a Grignard reaction of an aldehyde or ketone? Show all possibilities.



- 9.40 Which of the alcohols shown in Problem 9.39 could you make by reduction of a carbonyl compound? What carbonyl compound would you use in each case?
- 9.41 How could you convert bromobenzene into benzoic acid, $\text{C}_6\text{H}_5\text{CO}_2\text{H}$? (More than one step is required.)
- 9.42 Show the structures of the alcohols and aldehydes or ketones you would use to make the following acetals:

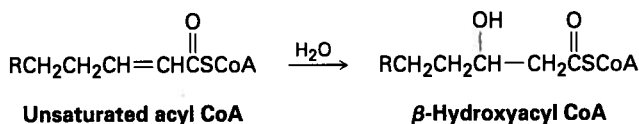


- 9.43 How would you synthesize the following compounds from cyclohexanone?

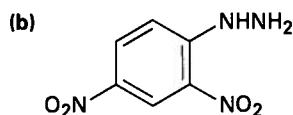
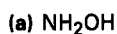


GENERAL PROBLEMS

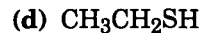
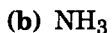
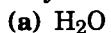
- 9.44 One of the steps in the metabolism of fats is the reaction of an α,β -unsaturated acyl CoA with water to give a β -hydroxyacyl CoA. Propose a mechanism.



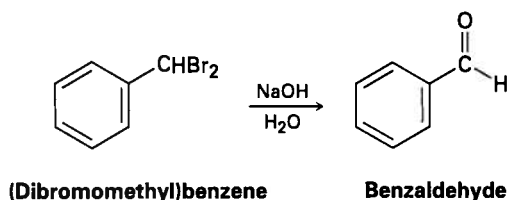
- 9.45 Show the products from the reaction of pentan-2-one with the following reagents:



- 9.46 Draw the product(s) obtained by conjugate addition of the following reagents to cyclohex-2-enone:

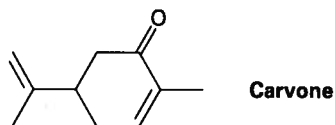


- 9.47 How can you explain the observation that the $\text{S}_{\text{N}}2$ reaction of (dibromomethyl)benzene with NaOH yields benzaldehyde rather than (dihydroxymethyl)benzene?



9.48 Carvone is the major constituent of spearmint oil. What products would you expect from the reaction of carvone with the following reagents?

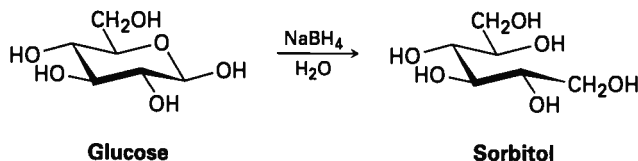
- (a) LiAlH_4 , then H_3O^+ (b) $\text{C}_6\text{H}_5\text{MgBr}$, then H_3O^+
 (c) H_2 , Pd catalyst (d) CH_3OH , H^+



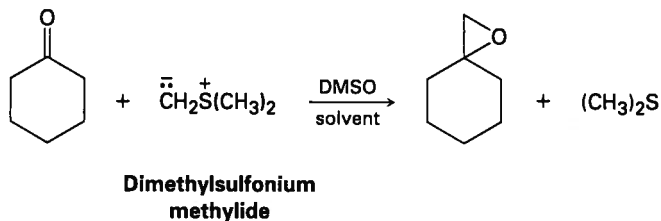
9.49 Treatment of an aldehyde or ketone with a thiol (RSH) in the presence of an acid catalyst yields a *thioacetal*, $\text{R}'_2\text{C}(\text{SR})_2$. To what other reaction is this thioacetal formation analogous? Propose a mechanism for the reaction.

9.50 Treatment of an aldehyde or ketone with hydrazine, H_2NNH_2 , yields an *azine*, $\text{R}_2\text{C}=\text{N}-\text{N}=\text{CR}_2$. Propose a mechanism.

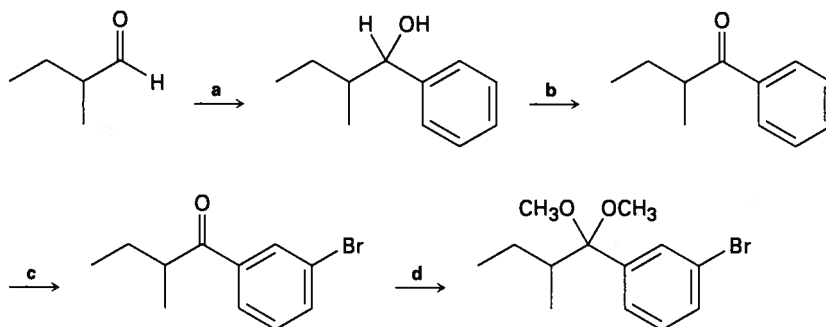
9.51 When glucose is treated with NaBH_4 , reaction occurs to yield *sorbitol*, a commonly used food additive. Show how this reduction occurs.



9.52 Ketones react with dimethylsulfonium methylide to yield epoxides by a mechanism that involves (1) an initial nucleophilic addition followed by (2) an intramolecular $\text{S}_\text{N}2$ substitution. Show the mechanism.

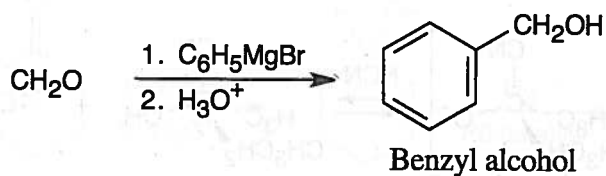


9.53 Identify the reagents **a** through **d** in the following scheme:

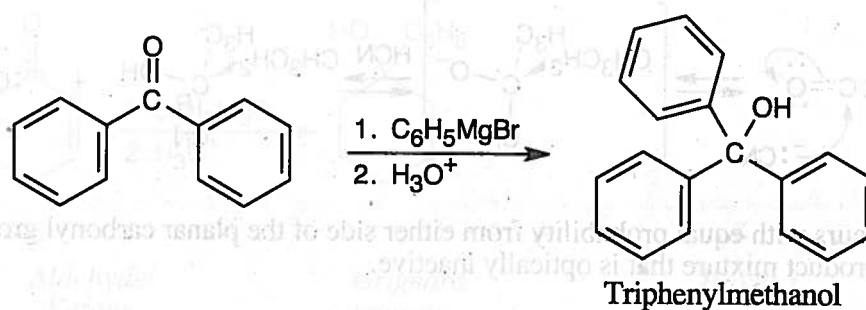


9.33

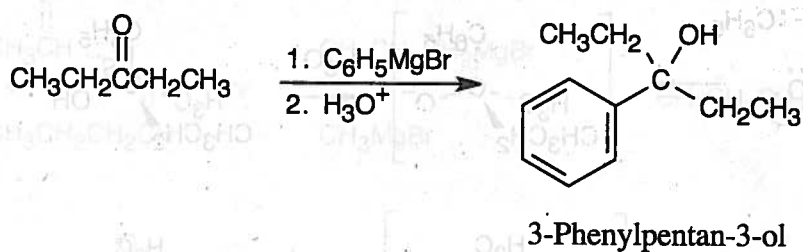
(a)



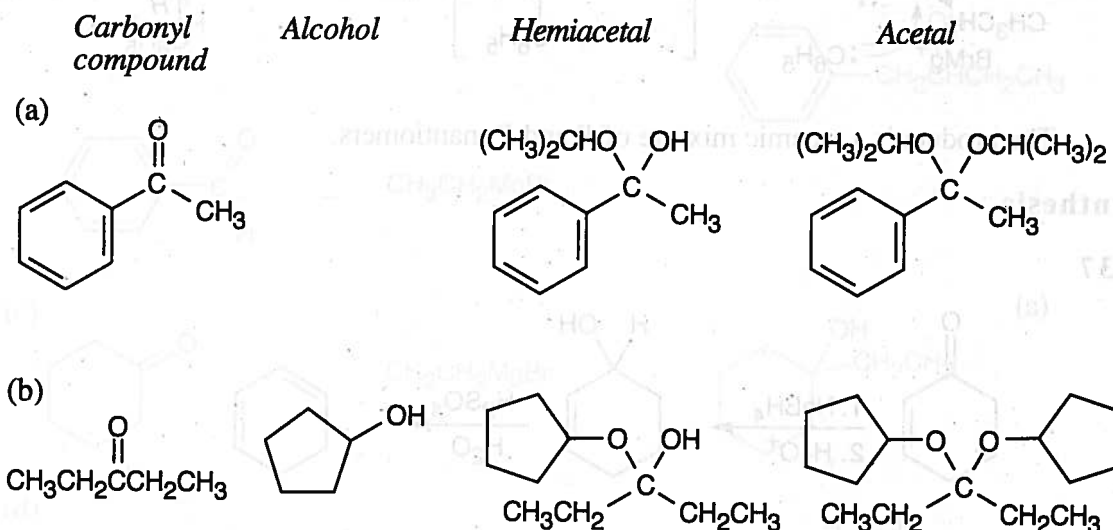
(b)



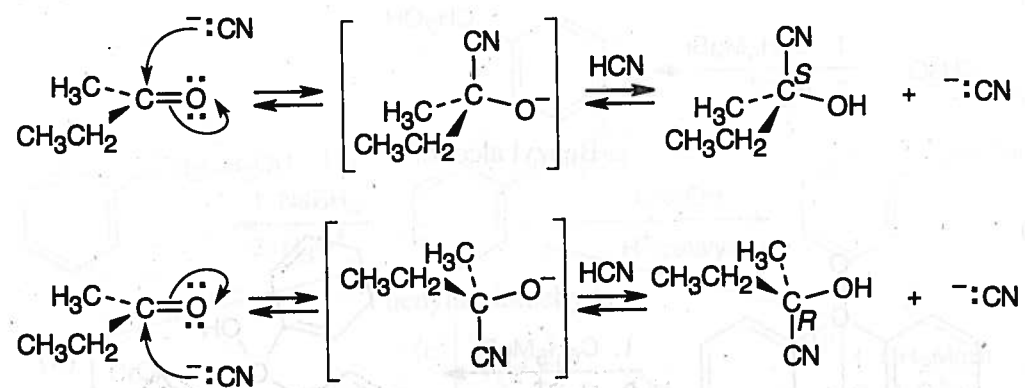
(c)



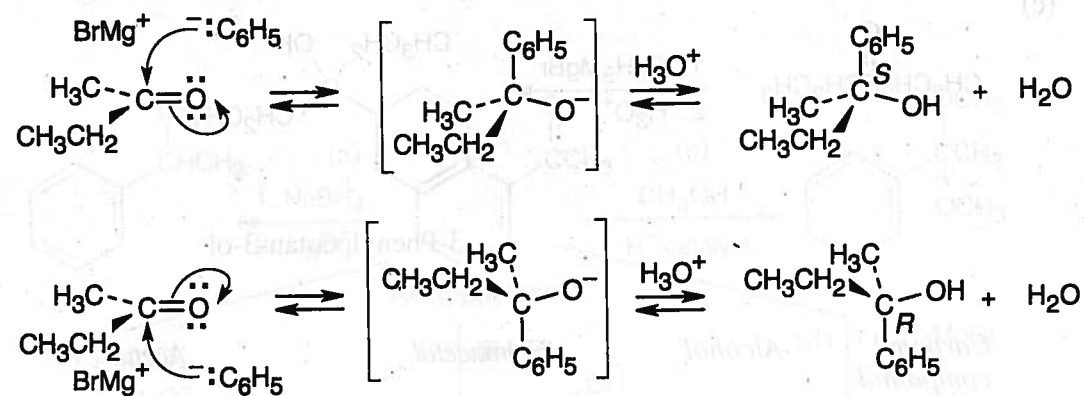
9.34



9.35

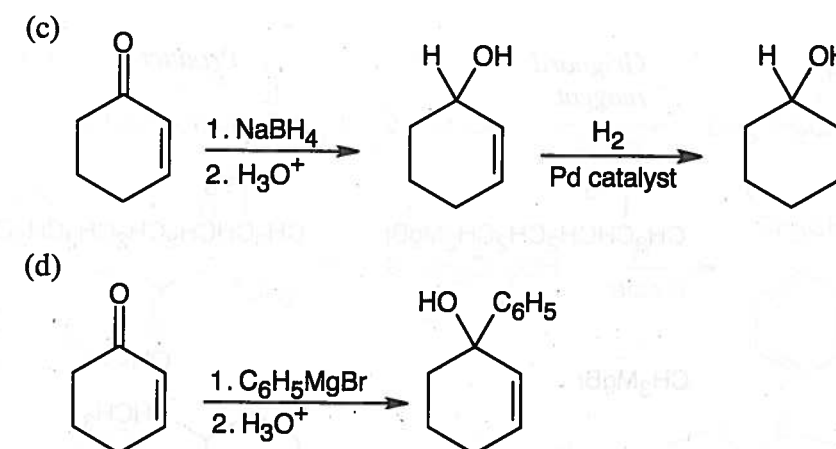
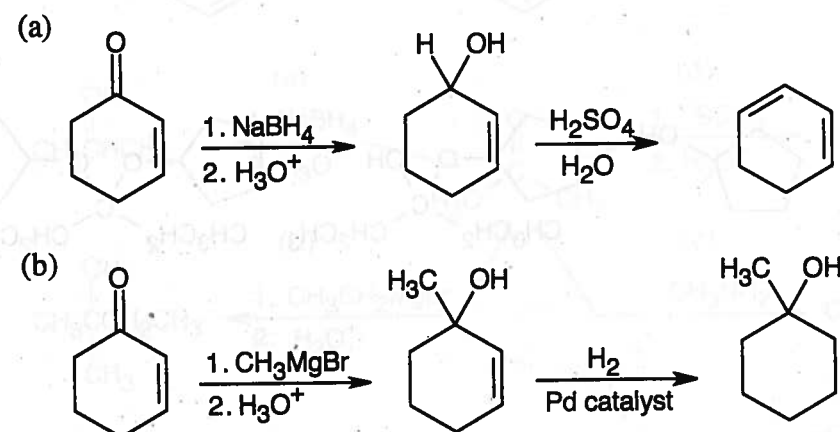


9.36

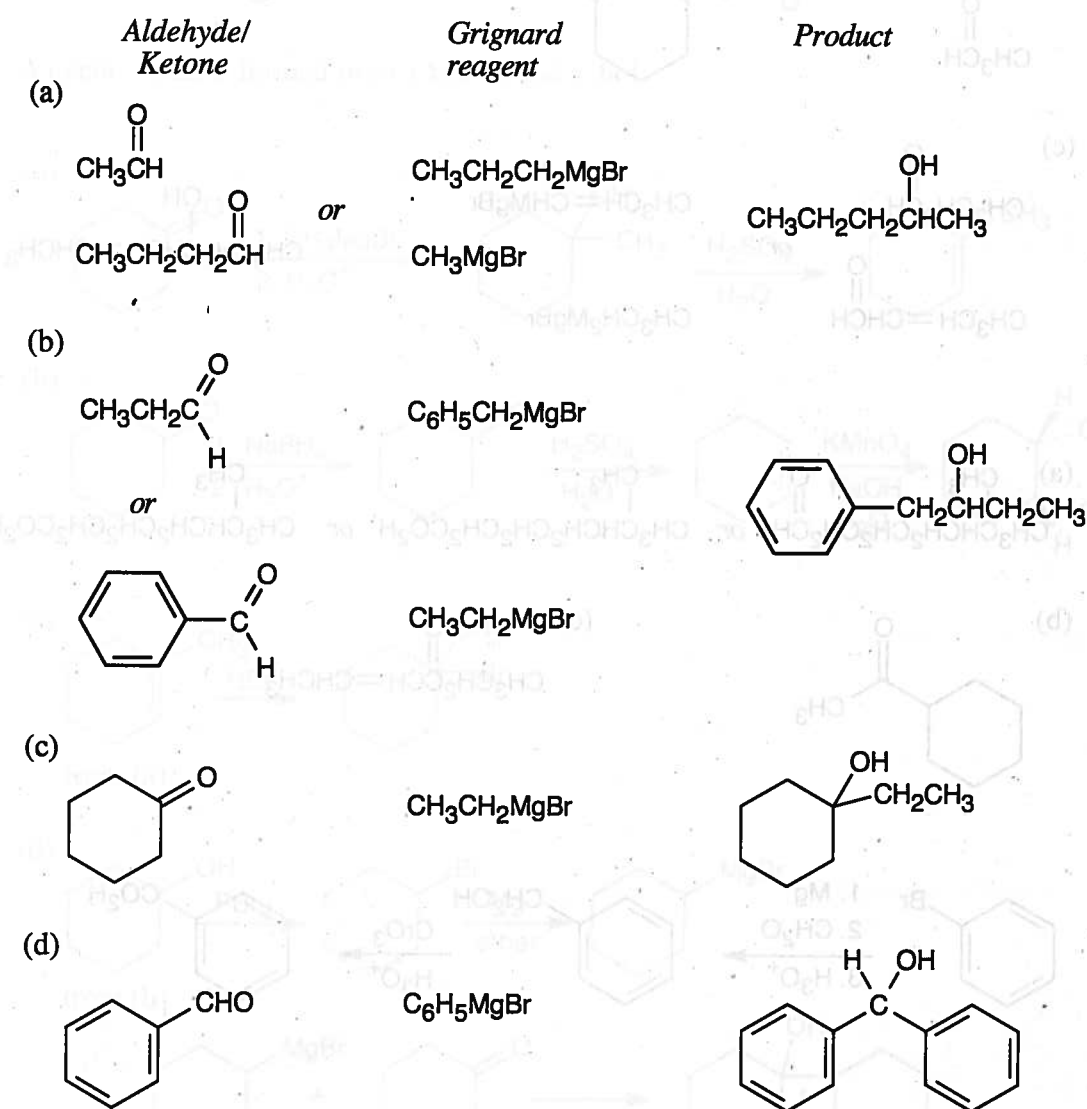


Synthesis

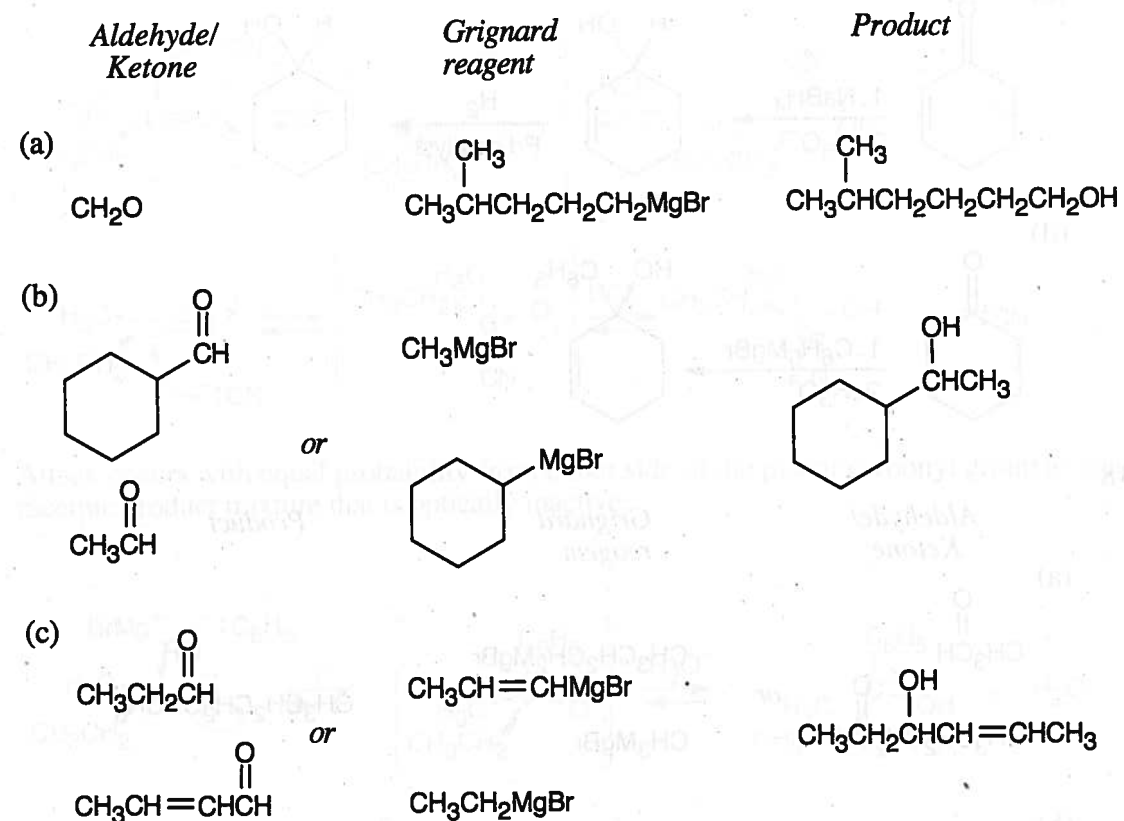
9.37



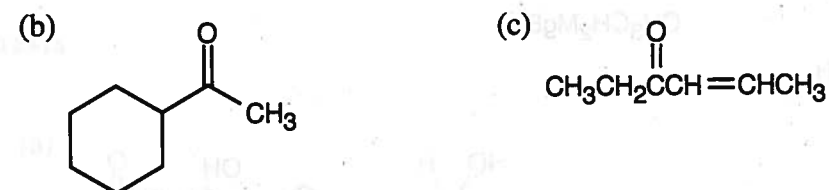
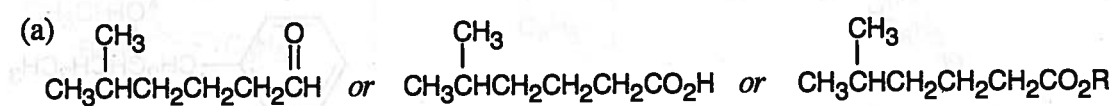
9.38



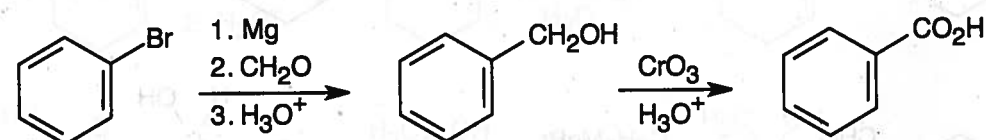
9.39



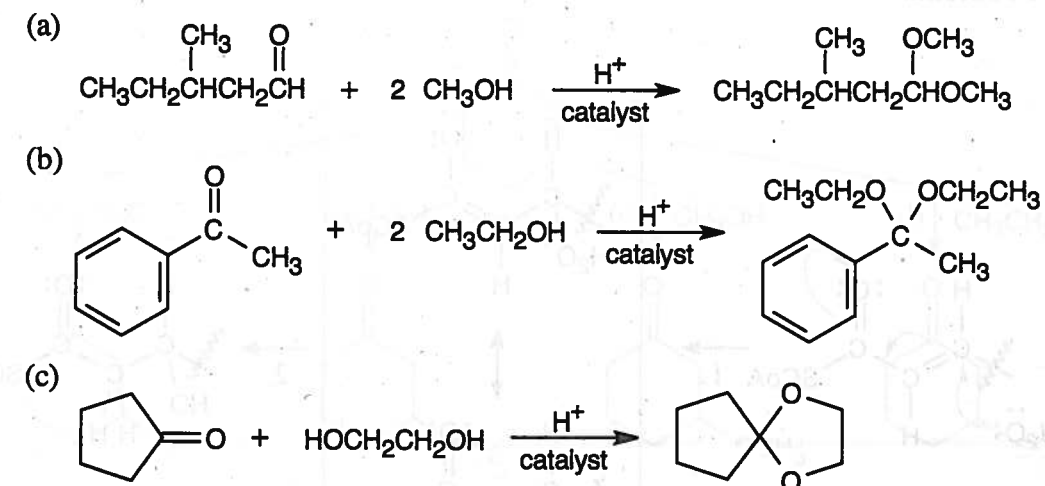
9.40



9.41

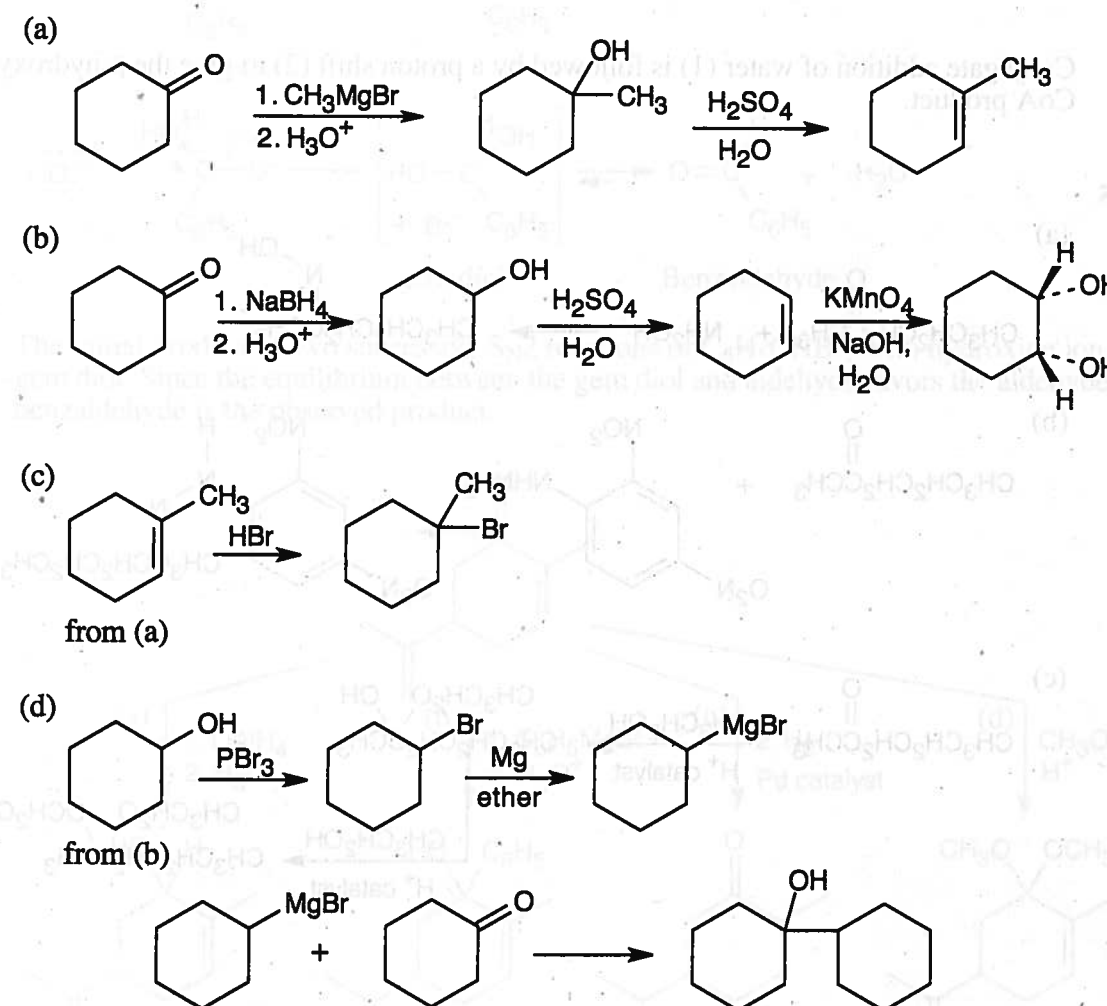


9.42



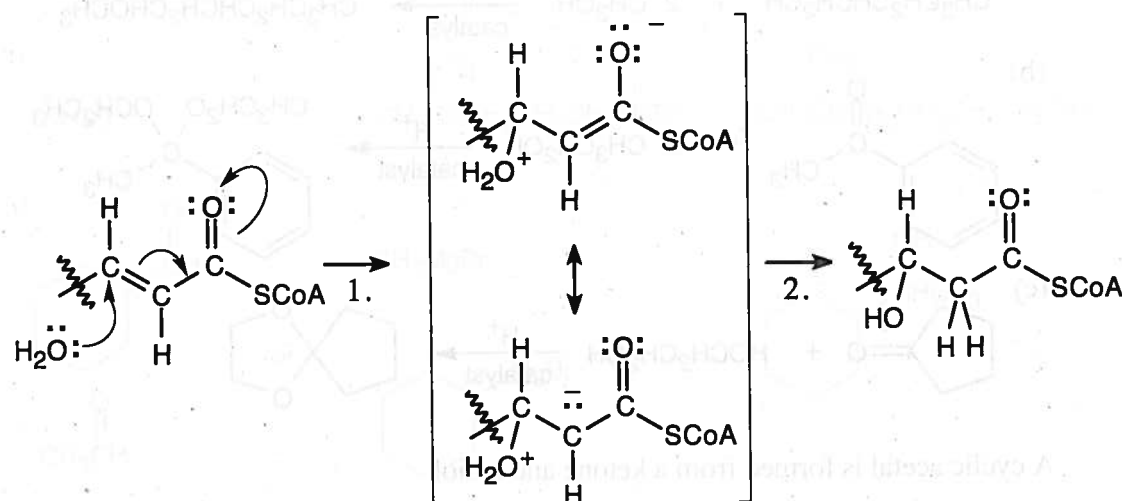
A cyclic acetal is formed from a ketone and a diol.

9.43



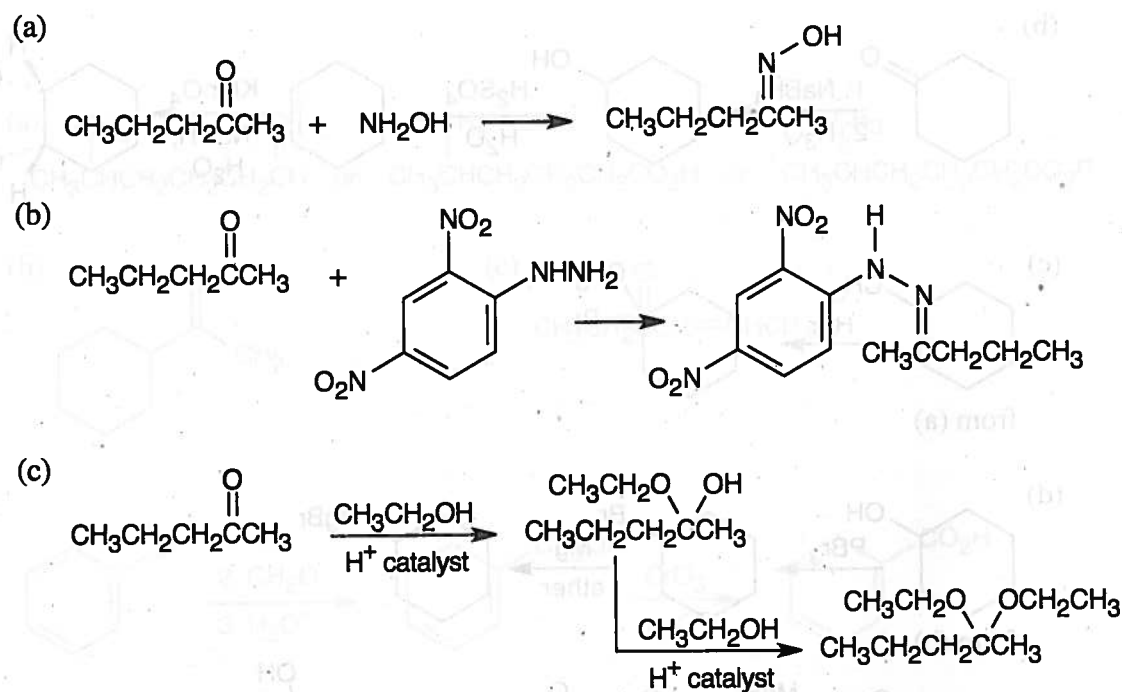
General Problems

9.44

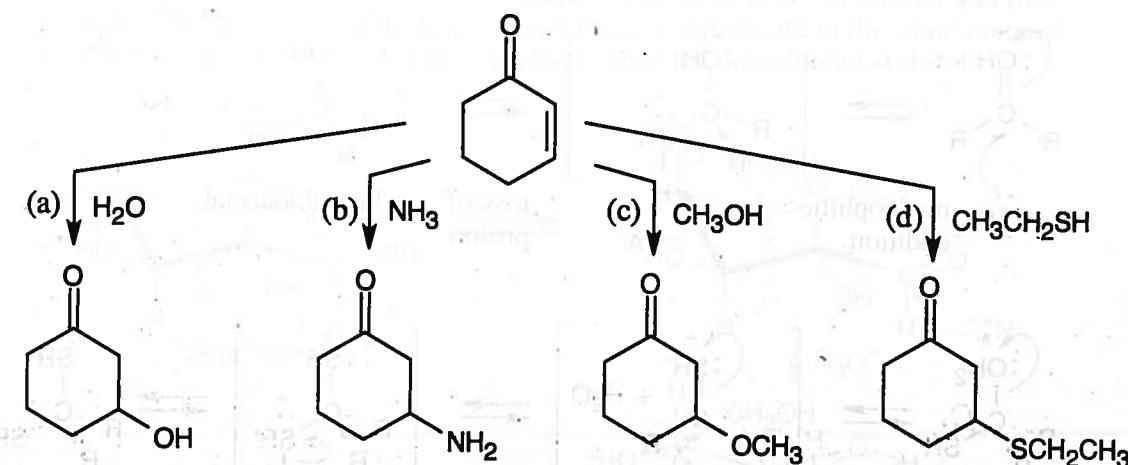


Conjugate addition of water (1) is followed by a proton shift (2) to give the β -hydroxyacyl CoA product.

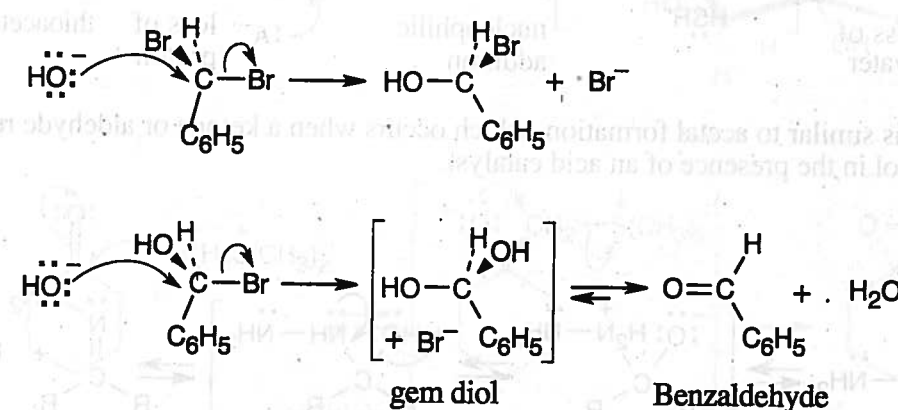
9.45



9.46

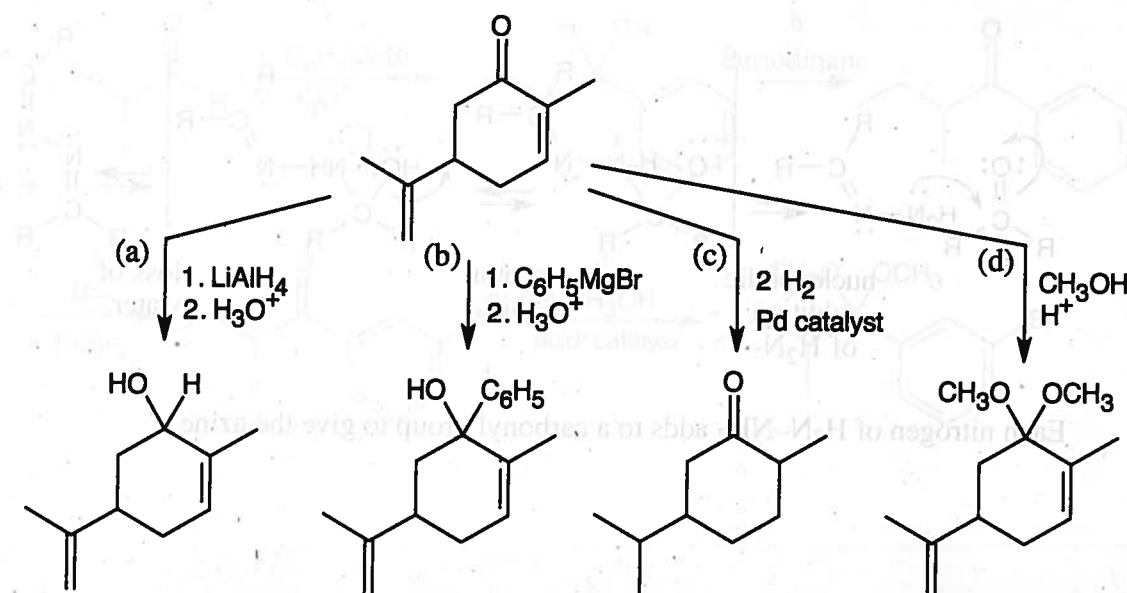


9.47

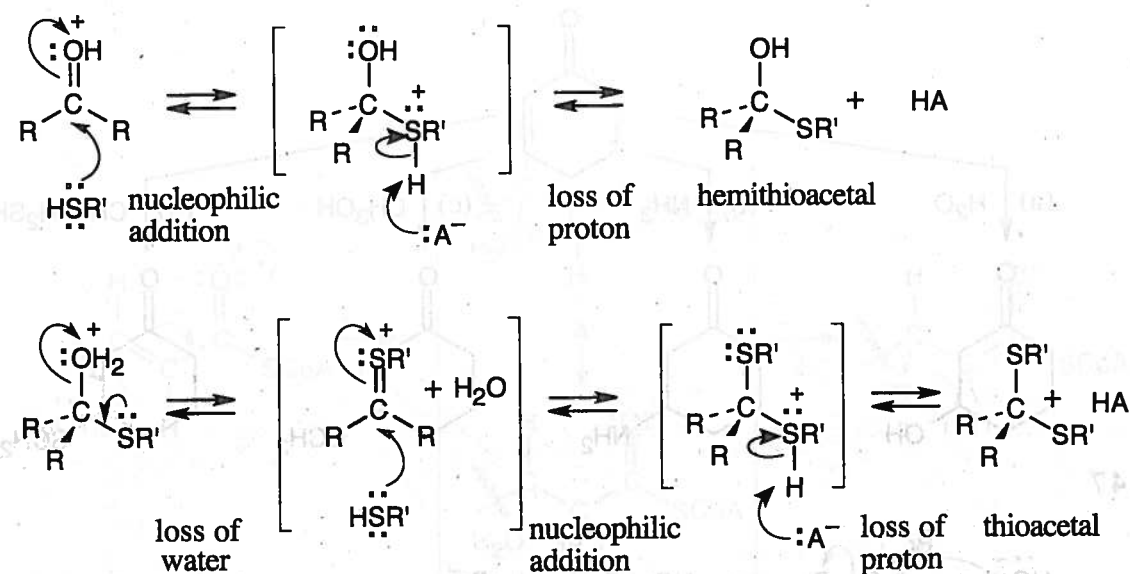


The initial product of two successive $\text{S}_{\text{N}}2$ reactions of $\text{C}_6\text{H}_5\text{CHBr}_2$ with hydroxide ion is a gem diol. Since the equilibrium between the gem diol and aldehyde favors the aldehyde, benzaldehyde is the observed product.

9.48

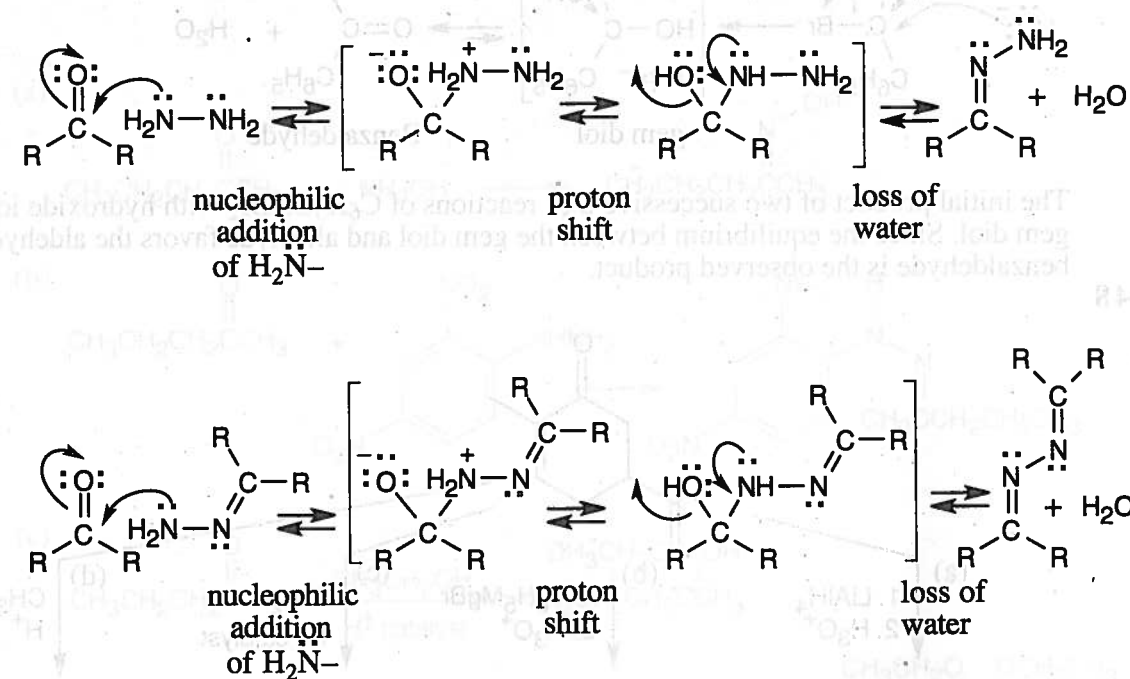


9.49



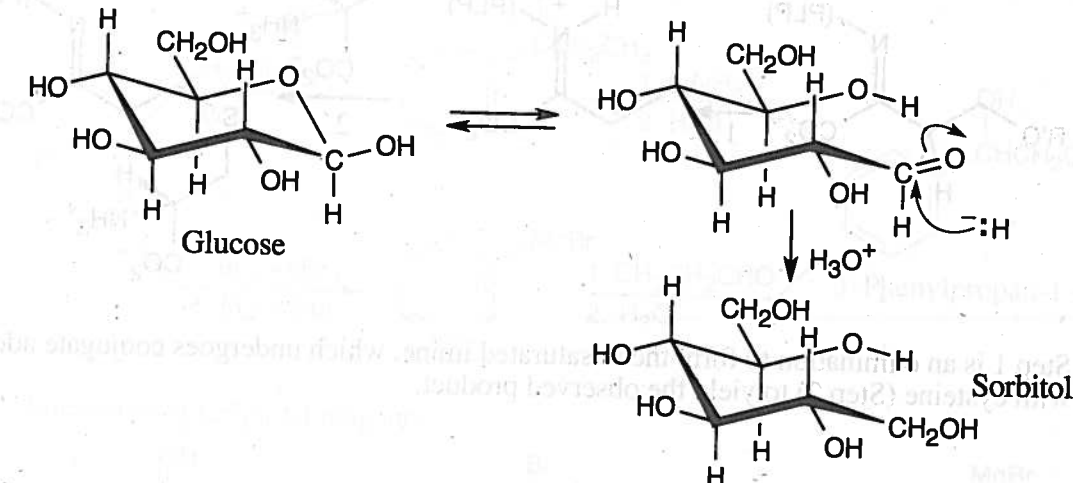
The reaction is similar to acetal formation, which occurs when a ketone or aldehyde reacts with an alcohol in the presence of an acid catalyst.

9.50

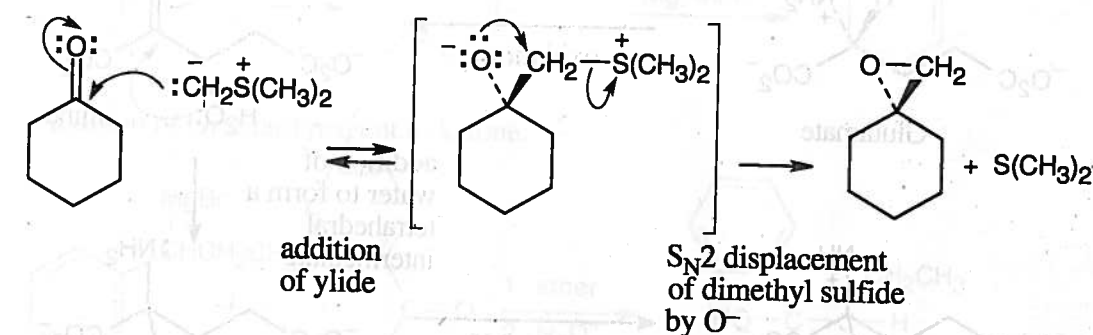


Each nitrogen of H_2N-NH_2 adds to a carbonyl group to give the azine.

9.51 Glucose is an aldehyde that exists as an equilibrium mixture of hemiacetal and free aldehyde. The open-chain aldehyde form of glucose is reduced in the same manner described in the text for other aldehydes to produce the polyalcohol sorbitol.



9.52



9.53

